VAN NOSTRAND'S

ENGINEERING MAGAZINE.

NO. CLXXXIV.—APRIL, 1884.—VOL. XXX.

STRAINS IN HIGH MASONRY DAMS, AND THE METHOD OF COMPUTING THEM.

By E. SHERMAN GOULD, C. E.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

THE designing of a masonry dam of moderate dimensions—say up to 50 feet in height—involves no particular difficulty. Not to speak of that sheet-anchor of the constructing engineer, the study of existing works, the resisting and destructive forces are so easily determinable, that very simple calculations suffice to fix the proper, or at least the safe, proportions in any case.

As we pass to greater heights, however, the subject becomes a more difficult one. Not only do we find fewer precedents, but other considerations, beyond the mere balancing of the inertia of the structure against the exterior forces tending to overthrow it or thrust it forward, enter the problem as essential factors, and render its solution a matter demanding a deeper study.

Thus, as we pile up stonework to a height of 100, 150, 200 or more feet, we find ourselves menaced by a danger heretofore safely ignored, namely, the possible crushing of the lower courses of our structure under its own immense weight. Mere weight, as regards inertia only, is an element of safety; in high dams it may become an element of danger.

This possibility of crushing presents itself under a two-fold aspect. If we suppose the reservoir to be empty, then the pressure tending to produce crushing is the weight of the dam itself alone. If we suppose it full we combine with this the horizontal thrust of the water, modifying the pressure and changing the position of its point of application.

If, in order to diminish the pressure upon the foundations when the reservoir is empty, we reduce the weight of the superincumbent mass by rapidly diminishing the thickness as it rises above the foundation, we will thereby increase the pressure when the reservoir becomes filled; for the resultant of pressures will be then carried nearer to the outer toe of the dam, concentrating the strain upon a small resisting area.

If, on the other hand, we increase the mass of our structure with the view of crowding the resultant of pressures, when the reservoir is full, back from the outer toe, then, when the reservoir becomes emptied, and the sustaining thrust of the water withdrawn, the dam is allowed to settle back, as it were, upon its foundations, and we have a perhaps dangerous stress nearer the inner toe.

Again, it does not suffice to confine our calculations to the lower course, or base, of our structure. Our work must be not only safe but economical, and the necessity of economy increases with its size and importance.

These being the facts, it will be readi-

ly conceded that the problem of determining the section of equal resistance—or, in other words, the section of maximum economy—of such dams, combined with a proper but not extravagant factor of safety, is one calling for deep and intelligent study on the part of the engineer.

It was to the solution of this problem that the French engineers charged with the work addressed themselves when the construction of a masonry dam 164 feet high was projected for the purpose of controlling the waters of the river Furens, near St. Etienne.

Let us glance for a moment at the requirements and data of the problem.

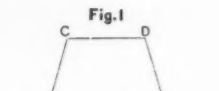
If we suppose a wall of homogeneous material and symmetrical transverse section—a "plumb" wall, for instance—we shall find the pressure upon the base, or any other horizontal section, to be uniformly distributed over the entire area of such section, the pressure per square inch being equal upon all parts of the same, because the vertical line drawn through its center of gravity cuts any and all of the horizontal sections which we may conceive to be passed through its mass in the middle.

If, however, from want of symmetry itself, or from being subjected to the action of exterior forces, or from any cause whatever, the line passing through the center of gravity of the mass situated above any given horizontal section, or the resultant of all pressures upon such mass if subjected to exterior forces, does not cut such horizontal section in the middle, the pressure per square inch is not uniformly distributed over the same, but reaches a maximum at the edge nearest to which the vertical line or resultant passes, and a minimum at that from which it is the most remote, the pressure varying according to some law which it is essential to determine.

This law is established by Monsieur Debauve in his *Traité des ponts en Maconnerie*, and the ensuing formulæ given, with some modifications in the 4th chapter of the 19th fascicule of his *Manuel del' Ingénieur des pont et Chaussées.*

I copy the following from a translation of the same made by me under instructions from Mr. Isaac Newton, Chief Engineer of the Croton Aqueduct, at the time when the projected extension of the New York City water supply was being studied in his office.

Fig. 1



"Let us consider (Fig. 1) a body of masonry, a wall for example, of which the transverse section made by a vertical plane is ABCD, and of which the base is represented in plan by the rectangle *mn pq*. On the median line of this rectangle there acts a vertical pressure P, applied in E. This pressure is distributed unequally at different points of the base, and it is important to ascertain the law of its distribution.

"Let the length *mn* of the mass be equal to unity; let *l* equal the depth AB of the base, and *u* the distance BE of the point of application of the pressure P from the exterior edge B of the prism.

"The elementary pressure at the point *p*, that is to say, the pressure per square foot, is given by one or the other of the two following formulæ:

$$(1)\ p = 2\left(2 - \frac{3u}{l}\right)\frac{P}{l}$$

$$(2)\ p = \tfrac{8}{3}\,\frac{P}{u}$$

according as *u* is greater or less than $\frac{1}{3}\,l$.

"The Discussion of the preceding formulæ gives the following results:

"When the point E is in the middle of the base, the pressure is uniformly distributed, and the elementary pressure at the point B, as elsewhere, is equal to $\frac{P}{l}$.

"As E moves from the middle of the base and approaches B, the pressure upon that edge augments, while the pressure upon the edge A diminishes.

"When BE, or *u*, is equal to $\frac{1}{3}\,l$, the pressure on B is equal to $\frac{2P}{l}$, that is to

say, to the double of what it was under an uniform distribution. The elementary pressure diminishes proportionally to the distances from B to A. It is nil at A.

"When BE becomes less than $\frac{1}{3}\,l$, the formula (2) is to be used. The pressure on the edge B augments continually, as the point E of application approaches this edge. The opposite edge A sustains negative pressures, that is, tension. But the mass is supposed to simply rest upon its base, BA, and no account is to be taken of cohesion. There can, therefore, be no tension at A, and consequently there is, starting from A, a certain zone sustaining no pressure, a zone of which the extent increases in proportion as E approaches B.

"The pressure, P, concentrates itself, therefore, more and more upon the edge B. It is distributed over a zone of which the extent is constantly diminishing, and when the point of application actually coincides with the edge B, the elementary pressure upon the same becomes infinite, as is shown by formula (2).

"If the point of application, measuring from the middle of the base, should progressively approach the inside edge, A, instead of the exterior edge, B, contrary results would occur. The elementary pressure would increase up to infinity at A, and decrease down to zero at B, over a zone increasing in extent from the edge B.

"The important point is to know the maximum pressure in each case, and for this the formulæ (1) and (2) suffice."

In conclusion, Monsieur Debauve remarks that: "It always remains true that, in adding to or taking from the mass, we affect the distribution of pressure, and may, therefore, by these means, approach as nearly as we please to a uniform distribution."

This law and its inferences, as given above upon the authority of Monsieur Debauve, form the key to the entire problem.

The calculations for the Furens dam were made by Monsieur Delocre, and are fully set forth by him in the *Annales des ponts et chaussees*, 1866. These calculations are somewhat intricate, and the matter may be better understood from the simplified processes—combined calculation and graphics—of Monsieur Debauve, as given by him in the volume mentioned above. It is not neccessary, however, except as a matter of very great scientific interest, to follow the steps by which the proper section for such dams was arrived at. When the investigation was commenced, it was impossible to say precisely what form of cross-section would be reached. The problem was; from among all conceivable forms, to detect that one which fulfilled the desired conditions. Mathematical processes, employed with an intelligence and skill far beyond any praise which I am adequate to bestow, lead up to the desired result as unerringly as if the question had been one of simple maxima and minima. The *general form* having been thus established, the problem is solved once and forever, and the only task left for succeeding designers is the safe, though humble, one of imitation.

I will now rapidly trace the successive stages of the investigation.

If we had only the weight of the dam itself to consider, that is, if our reservoir was to be always empty, it is shown that the proper form of cross-section would be a double, symmetrical logarithmic curve (Fig. 2); for this form secures a

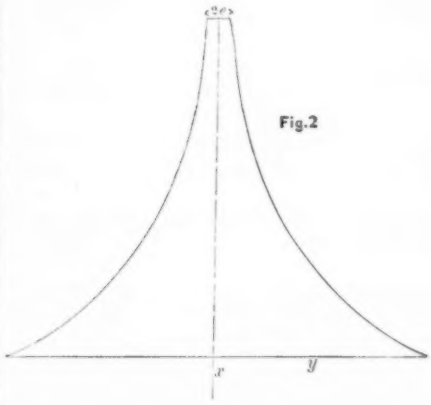


Fig. 2

section of equal resistance; the increment of surface increasing in the same ratio as the increment of pressure, and the weight would be uniformly distributed over any given horizontal projection.

The formula for this curve is as follows:

$$x=\lambda \cdot \mathrm{L}.\frac{y}{e}$$

in which

x=any vertical height corresponding to a given half width y.

λ=limiting height of a vertical wall sustaining only its own weight. This limiting height is determined by fixing upon a limiting pressure per square foot=R and dividing it by the density per cubic foot of the masonry $=\delta$, thus,

$$\lambda=\frac{\mathrm{R}}{\delta}$$

L=hyperbolic logarithm of y

e=any given half-width of top of wall. If unity be assumed, the above formula becomes

$$x=\lambda \cdot \mathrm{L}\, y.$$

If the reservoir were to be always full, then calculation shows that its proper form of cross-section would present a vertical face on the side next the water, and on the lower side a curve determined by the formula,

$$l=h\sqrt{\frac{\pi h}{\mathrm{R}}}$$

in which

l=length of any horizontal section.

h=height corresponding to same.

π=weight of cubic foot of water= 62.5 lbs.

R=limiting pressure per square foot.

This would give a cross-section such as is roughly shown in Fig. 3, where the top width has the theoretical dimension of zero.

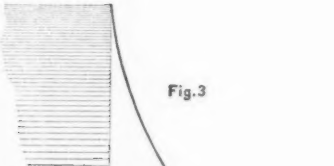


Fig. 3

But the reservoir is subject to be alternately full and empty, and moreover must have, in practice, some actual top width instead of the theoretical width = zero, shown in Fig. 3. We should have, therefore, to adopt a compromise section, similar to that shown in Fig. 4.

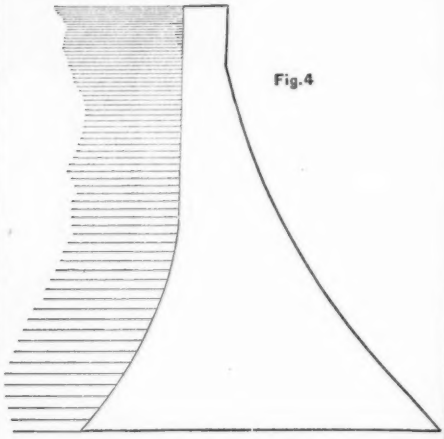


Fig. 4

These forms are general. The precise form decided upon for the Furens dam is shown in Fig. 5, and that of the Ban, built soon after that of the Furens, by the same engineers, is shown in Fig. 6.

As a basis of practical calculation, it is first necessary to fix upon the limiting pressure per square foot or square inch to which it is proposed to subject the masonry. In the designing of the Furens dam considerable caution was

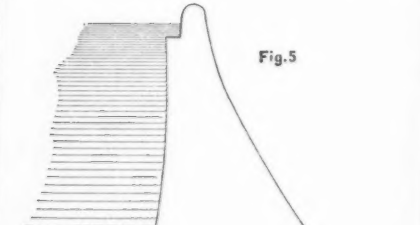


Fig. 5

exhibited in this respect, and the limit was fixed at 92.5 lbs. per square inch. In the case of the Ban dam, this limit was advanced to 114 lbs. per square inch. Observation shows that masses of masonry sustain much greater pressures without injury. On the other hand, instances are not wanting of crushing taking place in the lower courses of high buildings; and besides, the saving of masonry consequent upon adopting a high limit does not increase as rapidly as the pressure, in the case of dams. Thus, Monsieur Debauve shows that the saving of masonry between the limits of 86 and 200 lbs. per square inch per running foot of a dam 164 feet high, is only about one-quarter, while the pressure is considerably more than doubled. In other words, in this particular case, the saving is to the increased pressure about as 1 is to 9.

Sufficient has been now said to show how such dams may be designed. Instead of going through, in each case, with the original process of calculation in order to determine at once the proper form of cross-section, since we know that it must finally closely resemble that of the Furens or the Ban, it will be best to sketch a similar section, conforming to the desired conditions of height and top-width, and test it by the formulae (1) and (2), having previously determined upon the limiting pressure per square inch. If not satisfactory, a few trials will readily decide the necessary modifications.

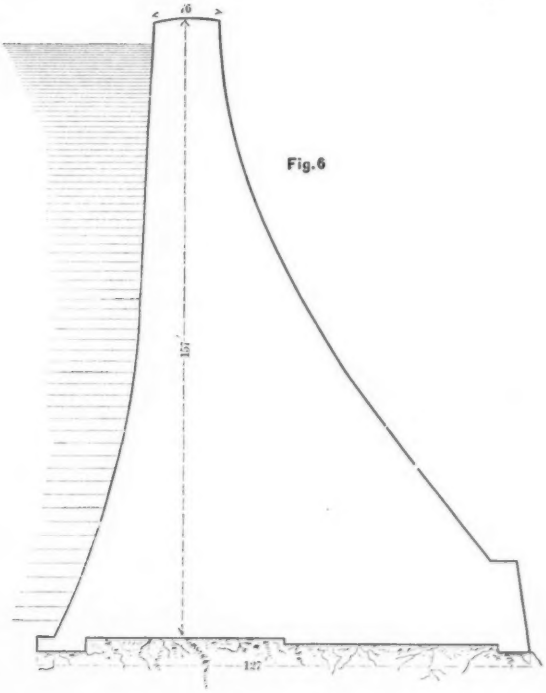


Fig. 6

As some engineers may not be familiar with the processes to be employed in testing the cross-section, I will give an example.

I will premise that for the purpose of calculation, it is convenient to transform the section from one bounded by curve lines, to one composed of rectangles and trapezoids. These can be made more or less numerous according as we wish to approach more or less closely to a curvilinear figure, or to test a greater or less number of sections.

Let Figure 7 represent the cross-section of a dam 120 ft. high, divided into three masses. Let AB and CD = 16 ft; EF = 60 ft., GH = 100 ft., AC = 30 ft., CE = 60 ft., and EG in vertical projection = 30 ft., and in horizontal projection = 10 ft. We will suppose the density of the masonry = 144 lbs. per cubic foot.

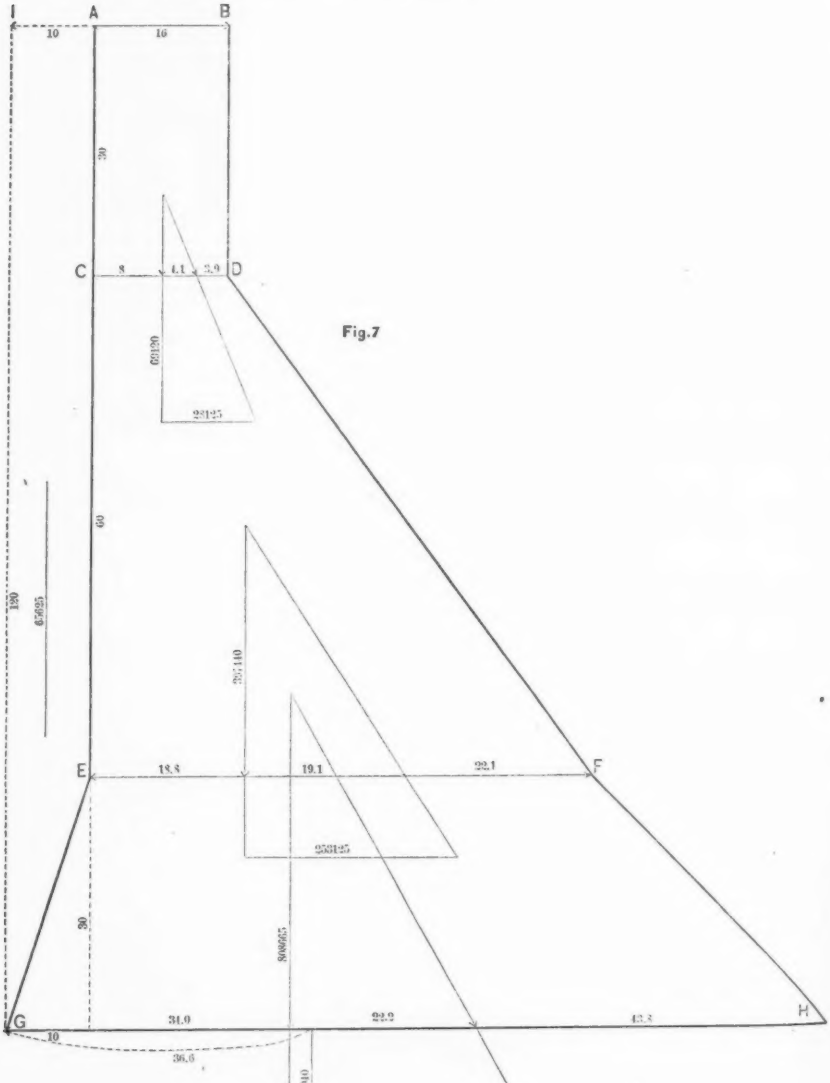


Fig. 7

The object of our investigation is to ascertain at what points the resultants of pressures cut the lines CD, EF and GH,

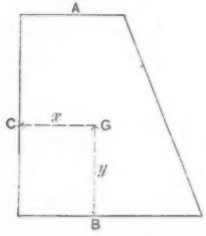
both when the reservoir is full and when it is empty, and their different intensities in order to apply the formulae (1) and (2.)

With the given data, the weights of the masses ABCD, CDEF and EFGH are respectively 69,120 lbs.; 328,320 lbs.; and 345,600 lbs., while the weight of the prism of water AEGI, at 62.5 lbs. the cubic foot, resting on the sloping face EG, is 65,625 lbs.

We will first deal with an empty reservoir, and proceed to fix the position of the vertical lines passing through the different centres of gravity. There are several ways of determining the centre of gravity of any given figure; one is to operate mechanically by suspending a piece of card board or other suitable material, cut into the form of the figure. But I think calculation, when it can be easily done, or otherwise one of the well-known graphic processes, is much preferable.

Thus, let Fig. 8 be a trapezoid having the two horizontal sides A and B, and

Fig. 8



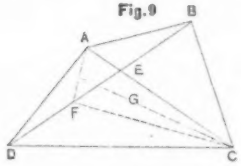
the vertical side C. Then the co-ordinates x and y of the centre of gravity G, are given by the relations—

$$(3) \qquad x=\tfrac{1}{3}\left(A+B-\frac{AB}{A+B}\right)$$

$$(4) \qquad y=\frac{C}{3}\left(\frac{2A+B}{A+B}\right)$$

A convenient graphic process for finding the centre of gravity of any quadrilateral figure (Fig. 9) is given by Molesworth, from whose pocket-book the preceding formulae were also taken. Thus, "In any four-sided figure ABCD draw the diagonals, intersecting at E. Lay off DF = BE, and join FA, FC; then the centre of gravity of the triangle FAC is also the centre of gravity of the Figure ABCD," (marked G in the figure).

Fig. 9



In combining the successive masses, we will take their moments from the line IG passing through the inside toe of the dam. I give below the entire work. A little careful attention to what follows will render any lengthy explanation of the successive steps unnecessary.

The centre of gravity of ABCD of course, is in the centre of the figure. Hence, it is 8 feet from AC, and 18 from IG. The centre of gravity of CDEF is found by (3) to be 21.12 from CE, and therefore 31.12 from IG. The distances of the centre of gravity of AEFDB from IG and AE are therefore obtained thus:

18×69120	=	1244160
31.12×328320	=	10217318.4
397440		11461478.4
$\frac{11461478.4}{397440}$	=	28.84
Distance from IG	=	28.8 ft.
" " AE	=	18.8 ft.

Again, the distance of centre of gravity of EFHE is found graphically to be 45.5 ft. from IG. The distance of centre of gravity of the entire section AEGHFDB from IG, is therefore:

397440.....		11461478.4
45.5×345600	=	15724800.0
743040		27186278.4
$\frac{27186278.4}{743040}$	=	36.59
Distance from IG	=	36.6 ft.

As we shall presently want the distance of the centre of gravity of the entire mass combined with the prism of water AIGE from IG, we will obtain it at once, thus: the distance of centre of gravity of AIGE from IG being obtained from (4) and found to be 4.76 ft.:

$$\begin{array}{rcl} 743040 \ldots\ldots\ldots 27186278.4 & & \\ 4.76 \times 65625 & = & 312375 \\ \hline 808665 & & 27498653.4 \end{array}$$

$$\frac{27498653.4}{808665} = 34.00$$

Distance from IG = 34.0 ft., all of which is shown on the figure.

We have thus the distances of the lines of vertical pressure from the inside face of the dam, when the reservoir is empty. We now must find the distances, from the outside face of the resultants of these pressures, when combined with the horizontal thrust of the water, the reservoir being full.

The thrust of the water, being at right angles to the line of action of the weights, cannot add to nor diminish the intensity of these last, but only throws their point of action further away from the water side of the dam.

The surface of the water being supposed to be level with the top of the reservoir, its thrust upon that portion of the dam situated above the line CD is given by substituting the height AC in the general formula

$$\frac{h^2 \pi}{2} = \frac{(30)^2\, 62.5}{2} = 28125 \text{ lbs.}$$

This thrust is applied at one-third the height AC = 10 ft., and is combined with the weight 69,120 lbs. of the mass ABCD, at the vertical line passing through its centre of gravity. By construction, we obtain the triangle of forces shown in the figure, and by scaling the same get the distance = 4 ft. from the point D at which the resultant cuts the line CD.

We may also obtain the distance very rapidly, and of course more accurately, by calculation. Thus, since the thrust of the water is applied 10 ft. above the line CD, the distance between the resultant and the vertical component at the line CD is given by the proportion:

$$\frac{x}{28125} = \frac{10}{69120};\ x = 4.1$$

The distance from D can then be obtained by addition and subtraction; thus:

$$16 - (8 + 4.1) = 3.9 \text{ ft.}$$

The distance of the resultant from F s found in a similar manner. Weight of mass AEFDB = 397440 lbs. Thrust of water 253125 lbs. Height of point of application of thrust of water above EF = 30 ft. Then

$$\frac{x}{253125} = \frac{30}{397440};\ x = 19.10$$

and

$$60 - (18.8 + 19.1) = 22.1 \text{ ft.}$$

For the distance from H, we have; weight of entire mass and prism of water, 808665 lbs.; thrust of water 450000 lbs. Height of thrust above GH = 40 ft. Then

$$\frac{x}{450000} = \frac{40}{808665};\ x = 22.2 \text{ ft.}$$

And,

$$100 - (34.0 + 22.2) = 43.8 \text{ ft.}$$

All these results are shown in Fig. 7, which is the reproduction of a tracing taken from the drawing upon which all the previous work was laid down. The cross-section is to a scale of 200 ft. to the inch; the triangles of forces are laid down on varying scales, decreasing as the forces augment. It is recommended to calculate all the necessary elements, and then check by construction.

We are now prepared to apply formulæ (1) and (2), and obtain the maxima pressures per square inch. Having calculated the distances so carefully, we see that it will be permissible to force the figures to even feet, except in one case.

We will first investigate the strains on the inside face, the reservoir being empty, taking the maximum pressures upon C, E and G successively.

The upper mass ABCD, being symmetrical, exercises an uniformly distributed pressure over CD, all parts of which sustain therefore a weight of 4,320 lbs. per square foot, or 30 lbs. per square inch.

In the mass AEFDB, the center of gravity is distant 19ft. from E. As this distance is less than $\frac{60}{3}$, we use formula (2), putting $u = 19$ and $P = 397440$; whence we obtain the maximum pressure upon E = 13945.26 lbs. per square foot, or 96.84 lbs. per square inch.

In the whole mass the line drawn through the center of gravity cuts GH at a point distant 36.6 ft. from G. As this distance is greater than $\frac{1}{3}^{0}$, we use for-

mula (1), putting $u=36.6$, $l=100$, and $P=743040$; whence we obtain the maximum pressure upon G=13404.44 lbs. per square foot, or 93.10 lbs. per square inch.

We will now investigate the maximum pressures upon D, F and H, the reservoir being full. As we have seen, the horizontal thrust of the water merely throws the weight further along towards the outside face of the dam, without increasing it.

The first distance being 4 ft., which is less than $\frac{1}{3}^6$, we use formula (2), putting $u=4$ and P=69120, whence we obtain the maximum pressure upon D=11520 lbs. per square foot, or 80 lbs. per square inch.

The second distance being 22, which is greater than $\frac{6}{3}^0$, we use (1), putting $u=22$, $l=60$, and P=397440, whence we obtain the maximum pressure upon F=11923.2 lbs. per square foot, or 82.8 lbs. per square inch.

The third distance being 44, which is greater than $\frac{1}{3}^{0}_{0}$, we use (1), putting $u=44$, $l=100$, and P=808665, as we must now employ the weight of masonry augmented by the vertical component of the prism of water resting upon the oblique face EG. We thus obtain the maximum pressure upon H=10997.84 lbs. per square foot, or 76.37 lbs. per square inch.

In examining these results it will be seen that while the pressure is nowhere excessive, it is greatest at E and F. If it were thought best to bring the section into one of a more uniform resistance, a slight modification, when it is so nearly correct, will suffice. Even merely joining the tangents by curves would produce a quite perceptible effect.

It will be perceived that the ordinary calculation of the overturning and static moments is passed by in this investigation. It is implicitly included in the process used, and need not be considered separately. It is well, however, to see that the frictional resistance of 75 per cent. of the weight be sufficient to neutralize the tendency of the horizontal thrust of the water to provoke sliding.

In the preceding calculations the actual weights have been used. It simplifies the work very much, however, to consider only the areas, assuming the weight of a cubic foot of masonry to be equal to unity. The area of water must then be affected by a coefficient; in our example the proper coefficient would be $\frac{62.5}{144}=0.434$. Our assumed density of masonry being the same number of pounds per cubic foot as there are square inches in a square foot, still further simplifies the calculations, as we may use the areas instead of weights throughout, getting our answers directly in lbs. pressure per sq. inch.

Thus, to calculate the maximum pressure upon H: The total area of cross section =5160 square feet. Area AIGE of water, reduced to equivalent area of masonry= $1050\times0.434=455.7$, making a total area =5615.7. Using this as the value of P in formula (1), we obtain at once $p=76.4$ lbs. per square inch, as before.

Other simplifications, or convenient modifications, may suggest themselves in practice. Thus, it will be found, I think, more convenient to write formula (1) in this form:

$$(5) \qquad p=2(2l-3u)\frac{P}{l^2}.$$

In using the design of the Furens dam as a precedent for similar works, the exceptionally favorable site upon which it was built must always be kept in view. The "Gouffre d'Enfer," across which it is thrown, is a narrow gorge, showing exposed rock, or rock under a shallow cover, at the bottom and on both sides. It is so narrow and steep that the dam, seen in elevation, shows almost the form of a triangle with its vertex downward. Its height is 50 meters, and its length on the top 100 meters—only twice as long as it is high. In plan it shows the arc of a circle with its convexity turned up stream. It thus forms an arch, solidly abutted against the rocky flanks of the ravine, its short length enabling the principle of the arch to assert itself with effect.

The "Ban" dam is built on somewhat bolder lines, and under somewhat less favorable circumstances. Its total height is 47.80 meters, and its length, over all, about 160 meters. The ratio of height to length is therefore as 1 to $3\frac{1}{3}$. The masonry of which it is built seems to be of somewhat inferior quality. It is circular in plan, like the Furens.

GAS ILLUMINATION AND ITS ECONOMY.

By JAMES CHEESMAN.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

NEARLY ten years have passed since the electric arc light appeared on the market as a probable competitor with gas. Manipulators of stock, and the varying conditions of the public faith in the new illuminant have left gas stock in pretty much the same position as it was when the markets were first disturbed. The public have seen many and various installations of electric light plants for private and public purposes. The new light has made its way in the face of great obstacles, it has scored many successes, has enabled a few to make fortunes, has shown its shortcomings and its susceptibility of improvement; and it has also indicated very distinctly what its future is to be and how it may be related to gas as a co-worker, friend and competitor. Gas managers have ceased to tremble, the public mind has regained its balance, and the two systems of lighting have settled down to quiet and sober work. Each has its own appointed sphere, each its peculiar merits, and if one is capable of developing greater efficiency as an illuminant, so also is the other; if gas can boast of economy, it must not be supposed that its rival has attained finality in that respect either. Physics and chemistry have not yet altered their last words on these subjects, and enterprise and industry still pursue their undisturbed course, working on gas with a faith and hope undaunted by the rivalry of its competitor. Electricians were not afraid to enter an untried field, and are not, therefore, likely to abandon the contest in face of the threatened economies. While this is so, it is also true that as each system of lighting pursues its way, they must in the nature of things continue to advance at very different rates of increase. It is not on the score of cheapness only that gas will advance in public favor, but because it can be made purer, be more easily distributed, and burnt in a manner to yield steady and incandescent light.

The improvements in the manufacture of coal gas have economy in their favor, nearly all the impurities met with in commercial gas being such as have a market value. Seldom a month passes without some record of advance being made in the gas works of European countries. In the United States, gas has always been high in price, owing partly to the higher cost of the raw materials used in the construction of the works, the higher rates of interest paid on capital, partly because legislation is less stringent in the public interest, and partly also to the fact that there is so much to divert enterprise and capital in the South and West. It is in England that the greatest economies have been wrought in the processes of manufacture. The present condition of the gas manufacture of Great Britain represents a degree of completeness unattained in few industries and surpassed by none. Whatever savings have been realized have always been the fruit of applied science and that in a prominent degree. In the best managed works, chemical analyses are constantly made of the raw materials, and the products of distillation. The purifying mediums are also subjected to close scrutiny, so that nothing is lost sight of which may help to improve the processes of manufacture. In a very large number of cases works have adopted the method of retort heating by gaseous fuel. Experience has shown the great economy of a uniform and controlled heat during the working of a charge. When the best possible form of retort is in use there is always a great strain from unequal and insufficient or excessive heating. The best remedy yet found for this defect is the gas furnace, which enables the engineer to work out a charge in about one-half the time it takes when raw coke is burnt. Under this system of heating, not only can a large charge be worked, but it can be done in less than half the time, the retorts have a much greater durability, and the yield of gas shows a larger percentage. Heating by gaseous fuel made from the coke has another advantage, which effects a saving of from 40 to 60 per cent. in the consumption of coke.

Instead of heating but one bench of retorts, as is done with the coke ovens, two may be worked from the single gas furnace. As an instance of what may be done by economical methods the City of Carlisle (Eng-) affords a first-rate illustration. The population is about 35,000 inhabitants: At a recent meeting of the gas committee of the Municipal Council, the chairman stated that in 1868 they obtained but 7,715 feet of gas from the ton (2,240 lbs.) of coal, while now more than 10,000 feet is the quantity, or 34 per cent. increase. In 1868, 2,251 tons of coke were made, against 4,703 tons for the year ending 1882, or double the quantity of coke for an increase of only one-third more coal. Formerly they had but ten gallons of tar, now they get thirteen, the ammonia liquor was 12 or 13 gallons per ton, now it is from 26 to 27. While these improvements have been effected, coal had advanced in value 20 per cent., and wages have also increased. In 1868 the price of gas in this place was 75 cents per thousand feet, now it is 50 cents, with a prospect of further reduction as soon as the additional improvements have been carried out for utilizing those by products now allowed to run to waste. Many such cases might be cited to show what can be done by improved processes of manufacture. Recent examinations of gas in large cities have revealed the fact that some of the impurities and diluents have been removed. A great point to be kept in view is the prevention as far as possible of those deleterious compounds, by guarding against leakages in the retorts, improper heating, and in efficient modes of purification. Much attention is being given to the separation of the carbon anhydride, sulphuretted hydrogen, carbon disulphide and sulphuretted hydrocarbons. The percentages of these substances are to some extent controlled by employing moderate temperatures for heating the retorts, but this does not get rid of the evil entirely, nor does the various schemes of after treatment which have lately been tried dispose of the difficulty. Just now the distinguished gas examiners of the English metropolis are establishing additional test stations with a view of more effectively checking the evil of impurities. Never was applied science more earnestly practised than now, and at no period of our history has sanitary requirements made stronger demands on the resources of manufacturers to reduce to the lowest minimum the impurities of their wares. The threatened competition of the electric light will be found to bear its quota of fruit in obliging gas engineers to get rid of the noxious matters associated with gas. It may be confidently anticipated that ere long the only impurities which the use of gas will be attended with will be those of carbonic anhyride and water—the products of combustion substances which may be ejected from our apartments by suitable appliances if we choose to go to the necessary expenses.

Another important consideration is the distribution of the coal gas from the works to the consumers. At present nearly every city gas works suffers from an excessive leakage, due mainly to imperfect joints in the mains. Wherever there is waste there is a cause of increased cost of the gas. In some places this is simply enormous, the loss by leakage reaching eight millions of feet in a single year, and this in a city of less than 150,000 people. At another place the reduction of the leakage was from 39 to 13 millions, a large waste for a city of ninety thousand people only. In Carlisle it was formerly 15 per cent., now it is 5 only. In Bradford (Eng.) it was high, now it is but 4 per cent. When all the items of waste in a gas works are considered it is not difficult to understand how it is rates are so high.

The combustion of gas for illuminating effects is a matter which the consumer must debate thoroughly for himself. Whether the article be good or bad, high or low in price, it will devolve on him to see that he burns it properly and under the best conditions for the emission of light. The ordinary gas burner is a poor tool at best, which neither governs consumption nor effects steady combustion. The result is very much what we see in the ordinary open fire or a device for burning crude coal with a supply of cold air. When pressures are unequal combustion varies, giving a great diversity of illuminating effects. Governed at the meter the waste under the most favorable circumstances is seldom less than 20 per cent., so that some form of efficient governor at the tip is the most

certain of complete working effect. A recent test was made with an ordinary Lara tip, 3 feet burner, and decided some very interesting results:

Common Open Burner.			G. Check Burner.				
Pressure in Supply Pipe.	Pressure Under Tip.	Consumed per Hour.	Pressure in Service Pipe.	Pressure Under Tip.	Consumed per hour	Illuminating Power.	Decrease of Candle Power.
4-10	3-10	3 feet.	10-10	4-10	3 feet.	8 c. p.	.016 p. ct.
7-10	5-10	4 "	15-10	8-10	4.7	11.21	.18 %
9-10	7-10	5 "	20-10	12-10	6	13.06	.32 "
11-10	9-10	6 "	25-10	17-10	7	11.2	.50 "
14-10	11-10	7 "	30-10	21-10	8	10.24	60 "
17-10	14-10	8 "	35-10	26-10	9	10.08	.65 "
20-10	16-10	9 "	40-10	32-10	10.5	10.05	.70 "

Efficient Governor Under Tip.

Pressure on Service Pipe.	Pressure Under Tip.	Consumed per Hour.	Illuminating Power.
10-10	3-10	3	9.6 c.
15-10	3-10	3	9.6
20-10	3-10	3	9.6
25-10	3-10	3	9.6
30-10	3-10	3	9.6
35-10	3-10	3	9.6
40-10	3-10	3	9.6

From the above tests it appears that ordinary burners are most wasteful contrivances for burning gas, and that in proportion to the loss by excessive consumption the illuminating power is decreased. Thus with a check burner, and an average pressure on the service pipe of 25-10, there was exerted under the tip an average of 17.14-10, and which consumed an average of 6.88 feet per hour, giving a light equal to only 10.54 candle power. The efficient governor under the tip would give for the same consumption a light of fully 25.5 candles. The waste in this case is clearly 60 per cent. It is easy to see that whatever improvements which may come to us with reductions of prices, unless our present modes of consuming gas be abandoned we shall not only pay much more than we ought but lose a tremendous amount of the illuminating power of the article. Again, at $2.50 per thousand a consumption of four feet per hour is exactly one cent, and equal to 13.5 candle power, burned under fair conditions. Ten such burners in operation for five hours per day means fifty cents per day or $45.50 cents per quarter. For families of small means this is a serious matter, and for the well-to-do and wealthy it is no less so either. For those who must spend $100 per month on gas bills it is above all important that they should avoid waste and get the greatest possible illuminating results from their consumption.

At a recent exhibition a well-known system of regenerative burner was displayed for the purpose of illuminating large spaces with steady and pure light. It was the invention of the late Dr. Siemens, the celebrated inventor of the regenerative gas furnace for metallurgical work. In this burner the gas is made to pass downwards, and is heated before combustion takes place. The air needed for combustion is also heated to a very high temperature before it comes into contact with the gas, and when combustion takes place an intensely white if not

incandescent flame is the result. An incandescent light is the great object to be aimed at, and is the point at which all gas engineers must aim if they hope to perfect gas illumination. Hitherto this burner has been suitable only for outdoor use, and has found no sphere in domestic service. If the principle can work so well for large open spaces there is little reason to doubt that it may work equally well for domestic requirements, when a burner of smaller capacity has been made. It ought to be quite possible to obtain from a burner of twenty-five feet per hour capacity an illuminating power of at least 100 candles. Experiment in better modes of combustion for light with ordinary gas may give fifty candle power from a burner consuming only ten feet per hour. What has been attained in heating results with the gas furnace may doubtless be repeated in illumination by the adoption of a well-devised system of regeneration of the gas and the air required for its combustion.

In the International Gas Exhibition, shortly to be held in Holland, we may look for some such results. The saving on consumption from the use of such a burner would be enormous, and would far outweigh any reduction in price if the present modes of consumption were maintained. Consider for a moment the comparative value of probable reductions of price and the saving from more economical consumptions. There is no reason why gas should be more than $1.00 per thousand in cities where the coal is laid down at $5.00 per ton and the consumption is 2,000,000 feet daily. In the large towns and cities of England the cost of the raw materials are not nearly so much less than they are here, as to justify the high prices of American gas. The following table will show how they are served as to quantities and prices:

City.	Population.	Consumption Daily.	Cost of Coal.	Price of Gas 1,000 feet.	Consumption per Capita.
Leeds.....	350,000	14,000,000 ft.	$2.50	44 c.	40 feet.
Bradford.....	200,000	6,750,000	2.50	60	33.75
Reading.....	42,000	215,786	4.00	78	5.13
Nottingham.....	180,000	3,158,000	2.75	60	17.5
Carlisle..... ..	35,000	406,300	2.75	50	11.6

Four of these five cities own their own works and run them to pay interest on the capital at four per cent., and to make a small profit which is used for improvements besides free lighting of the public streets. Reading works are owned by a company which is paid to do the street lighting, and makes profit enough to pay a dividend of eight per cent. only. It will be seen that coal costs $4.00 per ton, the daily consumption is less than a quarter million feet, and the average quantity used five feet only, while the price is seventy-eight cents the thousand feet. Suppose this little city be taken to represent the cost of coal to gas companies in American cities of more than one hundred thousand, and we take the per capita consumption at ten feet, then, with one million feet daily consumption any company might supply gas at $1.25, and pay 10 per cent. dividend. Now, if the reduction in the price is just fifty per cent. all round, how much better off will the average consumer be if we continue the present wasteful methods of gas consumption? Very little indeed. By the adoption of some efficient governor a saving of from 25 to 50 per cent. may be realized, and if some inventors will give us a regenerative burner for domestic use we may have an incandescent gas light of high power, which may enable us to enjoy an illuminating power of fifty candles with a consumption of ten feet per hour. The most efficient burner we now have hardly exceeds 18 candle power for five foot capacity, or barely 40 candle power for a ten foot burner. If we can regenerate the gas and air required for its combustion, it is a very moderate expectation to hope for an increase of only twenty per cent. in the lighting power of the illuminant. A chandelier fitted with three five foot burners of eighteen candle power would

consume 15 feet per hour and give the yellow light we now get of 54 candles. A ten foot regenerative burner of fifty candle power would give us a light nearly incandescent. If such can be realized, and there is little doubt that it can, our gas bills may be reduced to the extent of 75 per cent. on what we now pay. The cost of gas for light must soon undergo reduction, but so must the quantity consumed be cut down. Reform must commence first at the burner's tip, combustion must be more complete, and given a gas of fair quantity, the nearer we come to it the better and cheaper will be our light.

WHAT IS FRICTION?

From "The Engineer."

It is now just a century since Coulomb first investigated the laws of friction, and half a century since Morin made at Paris the series of experiments which has rendered his name immortal; and yet it would hardly be too much to say that it is only at the present moment that we are beginning to arrive at a clear conception of what we mean by so familiar a term. In saying this we by no means wish to insinuate the slightest disparagement of the illustrious physicists we have named. The fault lies not with them but with us. They had no desire—in the case of Gen. Morin, at least, we have his own authority for saying so—to impose their investigations on mankind as the last word of science, as absolutely and everywhere true, beyond as well within the limits within which they were tried. They claimed to have laid the foundations and to have laid them aright, but they looked for other workmen to come forward and complete the edifice. Until very recently, however, such workmen have been less than few, their contributions more than scanty. To the past generation of engineers, immersed in the practical details of construction, and in the thousand-and-one cases of commercial manufacture it was much easier to take Morin's results as they stood, and work by them, than to investigate the question any further for themselves. The same spirit of indifference has crept into our text-books; which quote Morin's results—with or without the courtesy of mentioning his name—as if they were no less rigidly true and general than the theory of gravitation itself. Yet it required the labors of a whole generation of astronomers to place Newton's theory beyond the reach of cavil; while the question of its possible limitation remains in dispute to the present day. In the sharpest contrast to this keen activity on the part of the votaries of science, the question of friction, whose practical importance it is scarcely possible to overrate, has been allowed to sink back, after the light flashed on it by the experiments we have referred to, into a hazy twilight, from which it is only just beginning to emerge.

To illustrate the present state of the case, let us begin with the treatment of friction, as it will be found in any standard book on "Applied Mechanics." First, we shall probably find a distinction drawn between statical friction, where the two surfaces are initially at rest, and dynamical friction, where they are already in motion. There we shall find a statement of what are called the "Laws of Friction," in something like the following terms:

(1) Friction, whether statical or dynamical, varies directly as the force which presses the two surfaces together.

(2) This force remaining the same, it is independent of the area in contact.

(3) Under the same conditions the value of dynamical friction is much less than that of statical friction, but it is constant at all velocities. To the statement of these laws may be added, in more elaborate and theoretical treatises—such as Moseley's "Engineering and Architecture"—a few words as to the limiting cases in which the laws cease to be exact, as, for instance, where the pressure approaches that of abrasion; and also of the state of things which prevails when the surfaces are fully lubricated with oil or grease, in which case

Morin concludes that the friction, whatever the nature of the surfaces, approaches to a constant value at between 7 and 8 per cent. of the pressure. Then will follow tables, taken almost exclusively from Morin's results:

(*a*) For plane surfaces at rest, sometimes dry, sometimes wet, sometimes lubricated.

(*b*) For plane surfaces in motion, under similarly varied conditions.

(*c*) For gudgeons or axles revolving upon their bearings, and more or less lubricated with ingredients of various descriptions.

In collections of formulae and rules, such as those of Molesworth and Rankine, these tables in an abridged form will be found to be the whole that is offered upon the subject. So deeply rooted is this "orthodox" doctrine, that we are acquainted with but one work on mechanics in which it is even hinted that the third law, as to dynamical friction, is by no means universally true; or that the friction of dry and lubricated surfaces are not phenomena of the same character. Yet scepticism on these points has long existed, but it is only within the last few years that it has broken out into open rebellion. We are now able to assert positively two facts of which the compilers of our text-books have not had the slightest glimmering. The first is that what is called friction in the case of dry surfaces, and what is called friction in the case of fully lubricated surfaces, are not analogous phenomena, but totally different in every respect, observing different and even contrary laws, and having nothing whatever, but an unfortunately chosen name, to bind them together. The second is that dynamical friction is constant for similar surfaces only within comparatively narrow limits of velocity; and that beyond those limits it either increases or diminishes, as the speed varies, in a very unmistakeable manner. It is evident that these two facts completely overthrow the sweet simplicity of the laws and tables of friction as they appear in our existing manuals.

It is worth while to dwell for a moment on the steps by which this change in our view of the question has been brought about. As long ago as 1852 the experiments made by Poirée and Bochet on shoe brakes and on the wheels of railway vehicles sliding on rails showed that the co-efficient of friction diminished very much as the velocity increased. Between the limits of 900 ft. and 3600 ft. per minute the coefficient of friction in the case of wheels sliding on rails diminished from .2 to .13. It is obvious that this is altogether contrary to the so-called law of dynamical friction, but it does not seem to have really awakened the sense of engineers to the question. There is nothing further chronicled until 1877, when Professor Kimball presented to the Royal Society a paper on the relations between friction and velocity. At ordinary speeds he found that the friction between pieces of pine wood diminished rapidly as the speed increased. Again, with a wrought iron shaft 1 inch diameter, running in a cast iron bearing and well oiled, an increase of velocity from 6 ft. to 100 ft. per minute caused the co-efficient of friction to fall as low as three-tenths of its first value. The same result was found with lower pressures, the pressure having in the first case been 77 lb. per square inch. About the same time Professor R. H. Thurston was carrying out in America a number of experiments intended to test, under varying conditions of speed, temperature, pressure, &c., the friction of well lubricated journals. These were subsequently published in his well-known book, "Friction and Lubrication." As to velocity, his conclusion was that the co-efficient of friction at first *decreased* with increase of velocity, but after a certain point *increased*, and that the point of change is different at different pressures and temperatures. On the whole he considers that, with well lubricated bearings, the friction increases with the velocity at all speeds exceeding 100 ft. per minute, and that the rate of increase is approximately as the fifth root of the speed. Almost contemporaneously with these researches of Prof. Thurston, another American, Mr. George Westinghouse, was carrying out, in conjuctio ı with Captain Douglas Galton, the magnificent series of experiments on the brake question which have since become classical under the name of the "Galton-Westinghouse Experiments." These threw much light upon the question of friction as between metals—generally cast iron and steel—which were rubbing over each other without lubrication, and at

very high speeds. In every case they showed a remarkable diminution of friction as the speed increased. This result held throughout the whole range of the experiments, in which the speed varied from 400ft. to 5300ft. per minute. It should be observed, however, that, owing to the nature of the instruments used, the observations only lasted half a minute, and it was found that during that time the coefficient of friction continued to diminish. The ultimate values assumed by it under different circumstances cannot, therefore, be exactly known; but from the appearance of the curves, obtained by plotting the results, it is clear that the values for high speeds would still be much smaller than for low speeds. Professor Kennedy has deduced from the experiments the result that the coefficient of friction was sensibly less at high than at low pressures, and that between the wheels and the rails—where the pressure was, no doubt, far greater than that on the brake blocks—the friction was not more than one-third of the amount found for the latter. This experiment is in accordance with Professor Thurston's results as to pressures, with ordinary velocities and loads; but the latter found that after a certain point a change took place, and further increase of pressure occasioned an increase in the friction. These results varied greatly under various circum stances, and they applied to lubricated journals, which, as we have seen, are really in altogether different circumstances from those of dry friction, as illustrated by the behavior of brake blocks.

Such was the state of the case when the Institution of Mechanical Engineers took up the question. Their progress in determining it has certainly been of the slowest; but they have lately issued a report which consolidates and advances our knowledge of the question in a remarkable degree. The experiments, which were conducted with great care by Mr. Beauchamp Tower, were first directed to ascertain the friction of journals under the best possible circumstances of lubrication; in other words, with a journal running in what may be described as an oil bath. By this it is not meant that the journal was absolutely buried in oil, but simply that its lower surface was always in contact with fresh oil, the upper surface being that on which the pressure rested. The results of these first experiments were very remarkable. In the first place, it was found that the absolute friction, that is the actual tangential force per square inch of bearing required to resist the tendency of the brass to go round with the journal, was much smaller than had ever been suggested before, falling in many cases as low as $\frac{1}{1000}$ of the pressure existing on the same area; secondly, it was found that this friction was nearly constant under all loads within ordinary working limits, and certainly it did not increase in direct proportion to the load, as writers on friction have always assumed. It only began to vary considerably when the pressure became excessive, and then the friction rose very rapidly and the bearing heated and seized. From this result it was naturally deduced that the friction of bearings in such circumstances is rather liquid than solid friction. The theory of liquid friction is that it is independent of the pressure per unit of surface; is directly a dependent upon the extent of surface, and increases as the square of the velocity. In the case of these oil-bath experiments the friction, as we have seen, is nearly independent of the pressure, and it was also found to increase with the velocity, at least with speeds beyond 150ft. per second. The question of its variation according to the surface in contact was not gone into. As regards other results, it appears that an increase in temperature caused a very marked diminution in the friction. For instance, with lard oil, the coefficient with the temperature at 120 deg. Fah. was only one-third of what it was at 60 deg. Fah. This is in accordance with previous results, but shows remarkably the advantage derived from keeping bearings warm. Again, it was discovered, though by accident, that the pressure existing in the film of oil at the top of the bearing, where the external pressure was highest, was very large; indeed, so great as to force the oil up through a small hole against a pressure of at least 200 lb. per square inch, this pressure being more than double the mean load on the horizontal sections of the journal.

Subsequent experiments with ordinary methods of lubrication were by no means so satisfactory. The methods for introducing the lubricant, which are found to answer in the case of railway vehicles,

were found to fail altogether with this experimental journal. The cause is attributed, and no doubt rightly, to the absence of any shock or vibration in this case, such as goes on continually with a railway vehicle in motion. Fair results were, however, obtained by using an oily pad, pressed lightly against the under-surface of the journal. Although the supply of oil was so small that the journal scarcely felt greasy, yet the bearing carried about 500 lb. per square inch; but in this case the results approximated much more closely to the laws of solid friction. The coefficient was approximately constant at about 1 per cent. of the load, and no very definite variations of friction with the speed could be observed. The lubricating of the journal by means of side grooves fed from a siphon lubricator was also successful, and gave somewhat the same results, as far as the constancy of the moment of friction is concerned, with those obtained by the oil bath; but the absolute amount of the friction was about four times as great. Now it will be observed that these results are practically coincident with those of Professor Thurston, and may be taken to establish the first of the two facts with which we started, viz., that the friction of thoroughly lubricated journals is a totally different phenomenon from what is commonly known as friction between dry surfaces. A complete reformation in the treatment of the subject by text-books, and in the tables supplied therein, becomes an imperative necessity.

It will be observed that none of the investigators we have mentioned commit themselves to any theory as to the real nature of friction, whether solid or liquid; they are content to record facts, and leave others to frame hypotheses from them. It is, however, a well-known rule in the history of science, that the most fruitful progress in any department is made under the influence of some definite hypotheses, which it is the object of experimenters to confirm or disprove. Any physicists, therefore, who would put forward a good working hypothesis on the question of friction, or rather on the two questions of solid and liquid friction, would probably deserve well of the engineering profession and the world at large. There are plenty of problems, besides those we have indicated, which such a theory should embrace. For instance, we know of a case some years ago where steel tubes were manufactured by pulling an annular ingot of steel, in the cold state, through an opening in a plate, much after the fashion of wire-drawing on a large scale. In this process the finished tubes as they came out were generally perfectly cool, a result which probably few would have expected; on the other hand, one would occasionally appear which was sensibly warm, if not hot. But the cause of this was well known by the workmen engaged in the manufacture; it could always be traced to the presence of a minute piece of grit or other substance which had got into the hole, and had drawn a fine scratch upon the surface of the steel as it passed through. This is surely a remarkable fact. We do not at all say that it is impossible or even difficult of explanation, but we may at least commend it to the attention of our readers; and it would not be hard to mention many others of the same kind. To attempt an answer to these problems would lead us far beyond our present limits, but taken in conjunction with the experiments here described, they may at least justify us in putting forward the question placed at the head of this article, viz., What is friction?

M. Bourdalou, having stated in 1864, in his work, "Nivellement Géneral de la France," that the average level of the Mediterranean is by 0.72 metre lower than that of the Atlantic, this result was received with some distrust by geodesists. General Tillo points out now, in the last issue of the Russian *Izvestia*, that this conclusion is fully supported by the results of the most accurate levelings made in Germany, Austria, Switzerland, and Spain, which have been published this year. It appears from a careful comparison of the mareographs at Santander and Alicante by General Ibanez, that the difference of levels at these two places reaches 0.66 metre, and the differences of level at Marseilles and Amsterdam appear to be 0.80 metre when compared through Alsace and Switzerland; the Comptes Rendus de la Commission Permanente de l'Association Geodesique Internationale arrive at 0.757 metre from the comparison with the Prussian levelings, whilst the fifth volume of the "Nivellements der Trigonometrischen Abtheilung der Landesaufnahme" gives 0.809 *viâ* Alsace, and 0.832 *viâ* Switzerland. The difference of levels at Trieste and Amsterdam, measured *viâ* Silesia and Bavaria appears to be 0.59 metre. Each of these four results—0.72, 0.66, 0.80, and 0.59—having a probable error of 0.1 metre, their accordance is quite satisfactory, and we may, *Nature* says, admit thus that the average level of the Mediterranean is in fact lower by 0.7 metre than that of the Atlantic.

THE LONG-COLUMN FORMULA—A REVIEW OF THE CRITICISM OF PROF. BURR.

By S. W. ROBINSON, C. E., Prof. Mech. Eng., Ohio State University, Columbus, Ohio.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

IN this Magazine for November, 1883, Professor William H. Burr directed attention to a column formula first published in June 1882, and in terms not the most complimentary. Pressure of duties and engagements has prevented me from earlier pointing out the existence of overdrawn statements in the criticism, statements, indeed, which can easily be shown to be more applicable to the criticism itself than to the criticised.

Relative to applying the theory of flexure to columns, it will probably be admitted by most thinkers, that when the ultimate resistance of a column is less than that of a short block of the same section and material, it is because the column gets out of line under load. In support of this, it will be conceded that if the column has side stays so numerous as to entirely prevent the deviation of the column from a straight line, the supporting power of the piece will be that of a "block." It is equally certain that the stiffer the piece is, that is, the higher the co-efficient of elasticity, the more will it stand before the deviation from line occurs. Again, when a column fails, under load, it appears to be certain that the greater the ultimate compressive resistance of the material the greater will be the load-sustaining power of the column. These considerations warrant the conclusion that a rational formula for columns, applicable within certain limits of length over some function of diameter, should contain both the co-efficient of elasticity, and the modulus of crushing; except for such material as cast iron where, beyond a certain length, the modulus of tenacity displaces the modulus of crushing with some modification of form of expression. Again, beyond a certain length for a given diameter and section, deflection will become so great before any crushing occurs, that the failure, by deflection alone, of the column is wholly independent of the modulus of crushing, for which the formula will contain only the coefficient of elasticity to account for properties of the material, as shown by Euler's "the oldest column formula." These notions are sanctioned by eminent European authority, as well as formulas in accordance therewith containing the coefficient of elasticity and modulus of rupture, and reduced to practical form for cast-iron, wrought-iron, and wood. (See Sankey's Ritter, p 343). These formulas, as well as my own, are assailed to equal extent by the remark, "it is not possible to produce a formula," "based upon the common theory of flexure" that will give "results agreeing closely with actual tests" "unless the columns are excessively long." (Euler's formula being in mind in the last remark.) It is proposed to show, further on, by computed results compared with experimental ones, that it is, instead of "is not" "possible to thus produce a formula which shall represent with tolerably close approximation the ultimate compressive resistance" of bridge columns.

Professor Burr states that the common theory of flexure becomes only approximate for pieces under combined compression and flexure, at a limit, which according to experiment, is not below a length of two hundred radii of gyration of section. If he means by this that that theory is only approximate for beams in general, except within the elastic limit, he may be indorsed. But if he means that beyond this, the theory is not applicable to columns as well as to beams, there must be dissent, at least to such extent as flexure precedes failure, because the stresses are the same in kind in the column as in the beam, accompanied with a neutral axis, and terminate in the same way when carried to excess, viz.: by crushing or tearing of some portion of the cross-section of the piece. Hence the Professor should revise his statement, and make it read, "within 200 or more radii of gyration of section, the

common theory of flexure serves for columns as for beams carried to rupture, while beyond the 200 radii it applies as to beams within the elastic limit."

That the limit is not less than 200 radii, is probably true, my criterion formula (106) being that to fix its value. This for ordinary channel columns with flat ends, gives the length at about 250 radii of gyration. At this limit my formula gives the same results as Euler's. The latter formula, for failure of columns by springing out of line, is therefore to be used for computing columns of greater length, and the former for failure by combined springing and crushing for shorter columns, down to a length in the neighborhood of 20 to 30 radii of gyration of section. Thus, instead of "proving altogether too much," the new formula proves about right; it being that upon which the criterion formula depends. Experimental tests will be cited in support of the same point further on.

Another objection to the new formula is in the form of a doubt of its agreement with experiment through a wide range of length over radius of gyration, the range which I have previously cited being regarded as too limited. Though this range cited reaches about to 150, and includes nearly if not all bridge members, yet I shall, further on, show that it will work up to twice this value; indeed up to where the criterion calls for Euler's formula, from which limit the latter formula will be compared in continuation of length over radius of gyration to over 600.

One of the strongest points which Professor Burr doubtless flatters himself for having made, is to the effect that "as a matter of fact he takes the compressive resistance of a long column as given by the oldest column formula" (viz. Euler's), "and introduces it into his own equations," and hence if the resistance of the column is thus made to depend on "Euler's formula, what is needed if his eqs. (97), (98), (99), and (100)?" But, unfortunately for this flattery, Euler's formula need not be mentioned or thought of in producing my formula. Though it was used for convenience sake, yet the object was not to inoculate my formula with Euler's and thus impart virtue to the former. The object was to obtain an expression for the radius of curvature of the axis of the column at the point of greatest deflection.

To produce my formula without the slightest reference to Euler's, take eq. (93) as written by aid of Fig. 21, viz:

$$ad \frac{t}{\varepsilon} = \frac{y_1 + d_1}{\rho}, \quad . \quad . \quad . \quad . \quad (93)$$

to start with. Next, knowing that the axis of the column, when deflected under load, is a sinusoid, its equation may be written in the general form

$$y = a \sin v.$$

Now for Fig. 18, of the original article, regarding l as the length AB of the column with rounded ends, and taking the origin of co-ordinates at A, we have $y = o$ for $v = o$; also $y = o$ for $v = l$. To meet the last condition put

$$v = \pi \frac{x}{l}$$

giving

$$y = a \sin \pi \frac{x}{l} \qquad (a)$$

In this, $y = o$, for $x = o$ or for $x = l$, as required for this particular curve. The deflection at the middle of the column being greatest call it y_1 and for this x should $= \frac{l}{2}$. Introducing these for y and x, and

$$y_1 = a.$$

Putting this value of a, into equation (a), we obtain for the equation of the curve of the axis of the particular column of Fig. 18,

$$y = y_1 \sin \pi \frac{x}{l}, \quad . \quad . \quad . \quad (b)$$

Now, to find the radius of curvature for the middle point of the column to introduce in (93), differentiate (b) twice, and introduce the differential co-efficients into the differential equation for the radius of curvature, viz.:

$$\rho = \pm \frac{\left(1 + \frac{dy^2}{dx^2}\right)^{\frac{3}{2}}}{\frac{d^2y}{dx^2}} \qquad (c)$$

Hence from (b) we obtain

$$\frac{dy}{dx} = y_1 \frac{\pi}{l} \cos \pi \frac{x}{l}$$

and

$$\frac{d^2y}{dx^2} = -y_1\frac{\pi^2}{l^2}\sin\pi\frac{x}{l}$$

whence

$$\rho = \frac{\left(1+y_1{}^2\frac{\pi^2}{l^2}\cos^2\pi\frac{x}{l}\right)^{\frac{3}{2}}}{y_1\frac{\pi^2}{l^2}\sin\pi\frac{x}{l}}$$

for the radius at any point. At the middle of the column $x=\frac{l}{2}$, and ρ becomes

$$\rho_1 = \frac{1}{y_1\frac{\pi^2}{l^2}} = \frac{l^2}{\pi^2 y_1}, \quad . \quad . \quad (d)$$

If the curve of the axis of the column be regarded as a circle instead of a sinusoid, with the origin of co-ordinates at the middle of the column and on the axis, we find the radius of this circle to be the radius sought. The equation of this circle is

$$y\,(2\rho - y) = x^2$$

or dropping y as small compared with 2ρ and, observing that $y=y_1$ for $x=\frac{l}{2}$, we obtain

$$\rho_1 = \frac{l^2}{8y_1} \text{ approx.}, \quad . \quad . \quad (e)$$

which is the same as eq. (*d*), except 8 takes the place of π^2; a difference due to the difference of the curves, and one which would not very much affect the results given by the final equation for columns.

If the curve of the column's axis be assumed to be a parabola with vertex at $\frac{1}{2}l$, we obtain

$$\rho = \frac{l^2}{8y_1} \text{ exact}, \quad . \quad . \quad (f)$$

Combining (*d*) with (93), we obtain an expression for y_1 which is free from ρ, and the same as (96) of the original article. That value of y_1 combined with (96*a*), viz:

$$t = \mathrm{T}y_1\frac{d_1}{\mathrm{I}_1} + \frac{\mathrm{T}}{\mathrm{K}}, \quad . \quad . \quad (96\,a)$$

results in an equation, which solved for T, is found to be my column formula (97) for round ends.

Had we combined (*f*), instead of (*d*) with (93), the resulting formula (97) would have had 8 in place of π^2, the latter being preferable from the fact that the elastic curve of the column is known to be a sinusoid instead of a parabola or circle. Euler's column formula is not required for showing this fact.

By comparing Fig. 19 with Fig. 18, the equation of the axis curve can be stated for flat end columns. Working out the radius of curvature similarly as above, and applying it in (93), the column formula for flat ends results. Likewise for flat and round ends.

Hence, Professor Burr's own expression becomes applicable here to himself, viz., "nothing could be more erroneous" than to state that my formula depends upon the ancient formula of Euler's, or that I take the compressive resistance as given by it and introduced it into my own equation. Also, the argument drops equally flat as found in the flimsy statement that "with a little consideration the reason is obvious" why my formula does not vary more from actual test results, viz: because it is "such a melange of Euler's formula, and of that for blocks as not to give results at random, but which are far enough from expressions of a true law." Professor Burr should try to avoid drawing statements with such haste, as to leave them with no foundations in fact, and take a second look before declaring my column formula simply Euler's, doctored with such a heavy dose of errors as not to give results at random.

Another example of this sort of argument is found in the statement that "a Phœnix column is equally liable to fail in any direction," ends flat, "while d_1 has different values in different directions." Testimony opposed to this statement is found in several good published authorities, among them the recent work by Prof. W. H. Burr on *The Elasticity and Resistance of the Materials of Engineering*, an authority which my opponent will doubtless accept as sound. On page 448, the formulas of C. Shaler Smith, C. E., are quoted, three of which are for Phœnix columns. These formulas, in conformity with the original Gordon's, contain d, the least diameter as is supposed, though no statement is found in the book to indicate what diameter. But as d is the only quantity in these formulas referring to the cross section of the col-

umn, it is certain that different result for strength is obtained when d is taken the least instead of another diameter. But as the formulas are given without adverse comment, the supposition is that they are acceptable to the author of the work, or that, so far, the column is most likely to deflect in the direction of its least diameter when failure occurs, this being the supposition respecting d in framing formulas containing the diameter. Other authorities than Gordon, Smith, and Burr indorse the same formulas, and also formulas differing in form of expression, as for instance Prof. Wm. Cain, C. E., in an article in this Magazine, Vol. XVII., p. 459.

But, without borrowing authority, if it be granted that the incipient flexure is as likely in one direction as another, as seems conclusive as far as considerations of the moment of inertia of the cross-section of the Phœnix column go, this one fact asserts positively the conclusion that the column will, as a general rule at least, commence fracturing on a remote edge of a rib in Phœnix columns instead of on the body of the tube between ribs; that is, where the radius is greatest instead of least or indifferent; because, with equal flexural tendencies, as for fixed or pointed ends, the column itself remaining fixed with respect to rotation, the slightly curved axis of the loaded column will admit of free rotation about the primitive unflexed axis, the latter line becoming an axis of a conoid of revolution described by the bent axis. Such rotary movement would find no resistance as far as the moment of inertia of the Phœnix section can affect it. But in this rotary movement of the flexed axis, those elements of the column which are most distant from the axis suffer the greatest strain due to the flexure, and hence as the strain is increased under the above action we must look for initial rupture on the edge of a rib, viz., at the distance d_1.

This is true for all column sections for which the moment of inertia is constant for all axes, such as the square section, even hollow, if the section of the cavity is similar and symmetrical with respect to a pair of axes at right angles to each other (Burr, p. 412). Hence, for a square column, the failure will, as a rule, be in the direction of the diagonal of the section, and in Phœnix columns it will be in the direction of the flanges, &c. These conclusions are supported by experimental test—the largest proportion of the Phœnix column tests cited by my critic, deflected in the direction of the flanges as the columns failed under load. See Trans. Am. Soc. C. E., Vol. XI., June 1882.

A Phœnix column laid across supports and loaded for transverse strain as a beam will, according to classic engineering literature, offer a resistance

$$\frac{RI}{d_1}=\frac{RAk^2}{d_1}$$

where R=modulus of rupture, I=principal moment if inertia of the cross section k=its radius of gyration, d_1=the distance to the most remote fiber on the side of initial rupture, and A=the section.

According to this the Phœnix column (beam) will be weakest when the flanges are in the plane of flexure, because I or k is constant for all positions of the cross sections, while d_1 varies with position of flanges, and is greatest when the flanges are in the plane of flexure as stated. When I or k is constant, and d_1 variable, the numerator of the above expression is constant, while the denominator is variable, making the expression least when d_1 is greatest. From this it is certain that if a Phœnix column (as such) is admitted to be in any measure subject to flexure under load, it must be more liable to fail by deflection in the direction of a flange than otherwise. It may be observed, further, that as a result of flexure, columns having the same constant I and variable $d_1 s$, the weakest will be those having the greatest value of d_1. For a single column the same may be stated with reference to k and d_1, as indeed is stated above for Phœnix columns; and, in general, the strongest column with given weight and length is nearly that which has the greatest value of k over d_1. These truths are not recognized in any of the 38 formulas found in a recently published work, or any other formulas which have come to my notice except the one called in question by my critic; truths which are as essential to correct column formulas, as are the fundamental truths to any correct formulas. These statements relative to d_1 apply only to columns varying in length

from 20 to 30 radii of gyration up to about 200 or 300.

I might indeed add that there are cases where the column will even be theoretically strengthened by cutting off portions of these outstanding flanges. This is the case with Phœnix columns when computed by my formula, the entire removal of the flanges affecting the strength but slightly. This is analogous to the strengthening of triangular beams by removal of a large percentage of the sharp edge. (See *Trapezoidal Beam* in Professor Woods' "Resistance of Material," about p. 170). Columns with triangular sections are also likewise strengthened, for deflection in a particular direction.

The remark that I "hold that Euler's formula contemplates only pure bending, and not combined bending and compression," is an error, and due to a most palpable oversight; that is, if the term bending is intended to signify deflection within the elastic limit, or an elastic spring of the column under load from its original line. This is plain from the fact that Euler's formula, (85) &c., in the original article, are deduced from equations worked out for simultaneous action of both compressive and transverse forces, from which the latter are finally dropped, and with the supposition that the former may deflect the column, causing flexure. That the column is supposed to fail by "springing out without breaking," does not debar the idea of compression. It is supposed that the column has failed when it has sprung badly out of line, even though no crushing has commenced and yet compression is experienced.

In comparing the formula with experiment, we are at liberty to use our judgment as to the proper value of the crushing resistance and coefficient of elasticity proper to the material in hand. The short blocks of Phœnix column section tested with the columns, indicate that a higher value of the resistance to crushing than 40,000 should be taken in computing for the 10 Phœnix columns cited. Using 42,000 for t, 31 million for E, and the distance to the edge of the flange for d_1, then by substitution into my formula, viz. (See *Science Series*, No. 60):

$$\frac{T}{K}=\frac{t}{1+\frac{d_1^2}{2k^2}\left(\sqrt{1+\frac{at\,l^2}{\pi^2\varepsilon d_1^2}}-1\right)} \quad (1)$$

we obtain

$$\frac{T}{K}=\frac{42000}{1.82\sqrt{1+\frac{1}{27000}\frac{l^2}{k^2}}-.82} \quad (2)$$

For both flanges cut off as suggested above, we obtain

$$\frac{T}{K}=\frac{42000}{\sqrt{1+\frac{1}{15000}\frac{l^2}{k^2}}} \quad (3)$$

both of which give practically the same values for the Phœnix columns cited, viz.:

$l\div k$.	Experiment.	Above Formula.
112	34,650	30,900
100	35,150	32,510
88	35,000	34,140
76	36,130	35,730
64	36,580	37,280
52	37,000	38,710
40	36,440	39,940
28	40,700	40,970
16	50,400	41,650
27	57,200	42,000

Mean discrepancy, 3778.

These results compare better than those presented by Prof. Burr in the November Magazine, due mainly to the fact that the constant t was taken too small for material found in Phœnix columns, and to an unsuitable value of d_1.

To indicate how the above results compare with such as obtained from other formulas for the same Phœnix columns, apply the Rankine formula,

$$\frac{T}{K}=\frac{36000}{1+\frac{1}{36000}\frac{l^2}{k^2}}, \quad (4) \text{ or } (114)$$

a general formula for wrought-iron columns. For this we obtain the

mean discrepancy=7645.

From a general formula much used by leading bridge companies, where the numerator of (4) is taken at 40,000.

mean discrepancy=4452.

And from a formula found in the *Elasticity and Resistance of the Materials of*

Engineering, page 442, especially for Phœnix columns, the

mean discrepancy = 3685.

Of these, only the latter result is found superior to that of the new formula, and in this case less than three per cent. It may be remembered that this superior formula is empirical, deduced from Phœnix column experiments, and not fit for other columns, nor claimed to be. This point is mentioned because a general formula is desirable for use in general specifications, into which it is not convenient to introduce several dozen formulas for as many cross sections which might be proposed by bidders.

In applying the new formula above, the ends have been treated as though fixed, for two reasons: first, because the columns were especially prepared by double riveting of segment joints at ends; and, second, because of the indifference of the flanges upon the results as pointed out above.

Doubts for the new formula were expressed by my critic for its having compared with experiment only through a limited range. To compare through a wider range, experiments of Hodgkinson and others are cited. First, from *Elasticity and Resistance of the Materials of Engineering*, p. 473.

CYLINDRIC TUBES WITH FLAT ENDS, RANGING FROM 20 TO 120 INCHES IN LENGTH, AND 1½ TO 4 INCHES IN DIAMETER.

$l \div k$.	Ultimate Resistance. Experiment.	By New Formula.	Rankine's, or Gordon's Formula.
240	14670	15430	13850
179	23206	19650	19000
160	21900	21370	21040
141	29800	23350	23190
120	27670	26490	26310
120	31180	25840	25710
90	29790	30000	29390
89	33300	30170	29510
87	26960	30440	29740
80	29330	31500	30570
80	30000	31500	30570
71	35100	32870	31580
67	26800	33470	32010
65	33330	33770	32220
60	34220	34510	32730
45	32200	36620	34080
45	36980	36620	34080
40	35660	37300	34470
40.	36000	37300	34470
39	36910	37380	34500
39	39570	37380	34500
35	36490	37820	34800
28	37390	38610	35210
21	48200	39030	35570

In adapting the new formula to these tubes, we find for all very nearly

$$\frac{d_1^2}{2k^2}=1\tfrac{1}{8}$$

$$a \text{ in eq. (1)} = \frac{4}{\left(1+\frac{k}{d_1}\right)^2}=1.44, \quad . \quad (117)$$

see original article, or *Science Series*, No. 60, p. 130, and taking $t=40{,}000$, $E=30$ millions, we obtain from. (1) for the resistance per square inch,

$$\frac{T}{K}=\frac{40000}{1\frac{1}{8}\sqrt{1+.000084\frac{l^2}{k^2}}-\frac{1}{8}} \qquad (4)$$

from which the quantities in the third column of the above table were computed.

From the table we find the

	New Formula.	Rankine's Formula.
Mean discrepancy regardless of sign.....	2501.	2967.
Dropping last result in the table do.	2211.	2541.

By noticing the value of l over k in the above table, it is seen to cover the entire range, and even more called for by Prof. Burr at the outset of his criticism, within which the stress is one of combined bending and compression.

But in the following table we find a still greater range of l over k, one indeed which goes beyond the limit set by the criterion formula, viz:

$$\frac{l^2}{k^2}=\frac{4}{a}\left(\frac{d_1}{k}+1\right)\frac{\varepsilon\pi^2}{t}, \qquad (106) \text{ or } (116)$$

(a being the same as in eq. (117)), below which value of l over k the new formula is to be employed, and beyond which Euler's. See *Science Series* No. 60, p. 109.

SOLID RECTANGULAR BARS WITH FLAT ENDS, RANGING FROM 4 TO 120 INCHES IN LENGTH, AND FROM 1″ SQUARE TO ABOUT 6×1 INCHES IN SECTION, INCLUDING 3×1, 3×½ INCHES, &c.

$l \div k$.	Experiment.	New Formula.	Rankine's, or Gordon's Formula.
643	2410	2550	2885
540	3380	3660	3956
414	4280	6220	6250
400	5630	6662	6604
311	9600	10680	9921
300	9750	11180	10290
272	10170	12400	11790
270	12970	12410	11900
207	18070	16040	16440
207	17700	16040	16440
206	16850	16110	16500
204	19990	16260	16620
200	17270	16560	17050
135	27770	23220	23900
104	29660	28000	27690
100	25330	28720	28180
50	34550	38790	33600
25	48680	43610	35390
13	50400	44500	35830

The experimental results in this table are found in the *Elasticity and Resistance of the Materials of Engineering*, p. 474.

The new formula takes the form

$$\frac{T}{K} = \frac{45000}{3\sqrt[2]{1+.00009\frac{l^2}{k^2}-\frac{1}{2}}} \qquad (5)$$

and the criterion fixes the limit at about $l=300k$, beyond which Euler's formula was applied, viz:

$$\frac{T}{K} = 1066000000\frac{k^2}{l^2}, \qquad . \quad . \quad (6)$$

In (5), a has the value 1.6.

In (6) this is omitted for the reason that no crushing or cocking is supposed to take place at the end bearing until after the column has sprung out in failure.

From this table we find the

	New Formula.	Rankine's Formula.
Mean discrepancy regardless of sign.....	2230.	2736.
Dropping last result in table, do.	2026.	2073.

The last result in this, and in the previous table, is proposed to be dropped, for the reason that Rankine's formula is considered by some as inapplicable below where $l \div k$=about 25 to 30.

The experimental results of the last table are those from which the constants in Rankine's (sometimes called Gordon's) formula, were in the main determined, giving the formula the specific form stated in (4).

It is therefore fair to this formula to compare its results with those by the new formula, as done in the 3d and 4th columns of the table.

We therefore find that the new formula, which was not made with a view to representing the experimental results of this table any more than all others, when placed in comparison with a formula which is made to do its very best by special calculation of its constants from these very results of test, does not appear at a very great disadvantage.

The high value of t=45,000 was taken, for the reason that the solid, flat, English bar iron experimented upon may be supposed to have a high crushing resistance.

Only one more comparison will now be made with experiment, and with other formulas. The results of experiment are quoted from the same work as previously, p. 476.

ANGLE BAR 3×3×$\frac{5}{16}$ INCHES WITH FLAT ENDS.

$l \div k$.	Experiment.	New Formula	Rankine's Formula	Special Formula
100	23600	25400	28180	23740
80	29480	29190	30850	26760
60	35380	33480	32730	30860
30	39400	37270	35120	43600
Mean of discrepancies regardless of sign		1530	3220	2895

The radii of gyration are taken for a diagonal axis, for the reason that it is less than that for an axis parallel to a leg of the angle which seems to be that given in the table quoted from. The last column is quoted from the same work, p. 477, computed by a special empirical formula probably by aid of radii given in the table.

In the new formula the compressive resistance is taken at $t=42000$. The angles being of English iron. Also $e=25000000$, $a=1.8$, $k=.6$, $d_1=1.22$, and

$$\frac{T}{K}=\frac{42000}{2.1\sqrt{1+\frac{1}{14000}\frac{l^2}{k^2}-1.1}}, \qquad (8)$$

These various comparisons will perhaps serve more satisfactorily than a theoretical discussion to show the capacity of the new formula, both as regards the range of l over k, and the form of cross section of column. In both respects they considerably extend the previous comparisons with over 30 full-sized columns given in *Science Series*, No. 60, and a good idea of how the formula meets this enlarged demand is at once obtained by reference to the magnitudes of the mean discrepancies.

INSTITUTION OF CIVIL ENGINEERS—ADDRESS OF THE PRESIDENT, SIR J. W. BAZALGETTE, C.B.

In addressing you as President of the Institution of Civil Engineers, I desire first to thank you for the honor you have conferred upon me by electing me to that position. For, although our Institution cannot boast of an ancient origin, its existence dating only from the year prior to the birth of our Most Gracious Majesty Queen Victoria, the presidential chair has nevertheless been filled by men whose names are engraven, not only in golden letters upon these walls, but will also be impressed upon the memory of future generations, as the pioneers of some of the greatest achievements which have been attained in practical science.

Forty-six years have elapsed since I was first elected a graduate of this Institution, and it has been my privilege, therefore, to have known it in its early days, and to have become personally acquainted with many of those honored men who have passed away, as well as with those who still remain as shining lights in our profession. But these recollections impress upon me the more deeply a sense of the responsibilities which attach to the position it has now become my duty to endeavor to uphold, and induce me to ask at your hands the same kind consideration and support throughout the coming session which you have always shown to my predecessors, and by which I have been placed in this chair.

Each annual report of the council forms a fit comment upon the rapid strides with which our institution has progressed. When I joined it in 1838 it was only twenty years old, and its members and associates did not include 351, including 33 graduates; whereas there are now 3,665 members and associates, and 778 students, making a total of 4,443, or between twelve and thirteen times the number registered forty-six years ago.

Whilst the profession of the engineer has been described by Tredgold in terse and emphatic prose, as "the art of directing the great sources of power in nature for the use and convenience of man," which has changed the aspect and state of affairs in the whole world, Pope has described its achievements in poetic language of great beauty in the well-known lines:

"Bid harbors open, public ways extend;
Bid temples, worthier the God, ascend;
Bid the broad arch the dangerous flood contain,
The mole projected break the roaring main;
Back to his bounds their subject sea command,
And roll obedient rivers through the land.
These honors peace to happy Britain brings;
These are imperial works, and worthy 'kings.'"

Had the poet lived until these days he would probably have added some lines on the influence of engineering on the health, comfort, and longevity of mankind. The rapid development of engineering science has, in fact, created the profession of the civil engineer.

In 1856 Robert Stephenson showed that in the United Kingdom alone there then existed 8,000 miles of railway, or a length equal to about the diameter of the globe, and the actual length of rail laid was sufficient to girdle the earth. 286

millions of pounds sterling, or one-third of the national debt, had then been expended upon these railways. But there are now over 18,000 miles of railway, nearly 10,000 miles of which are double, or more than double lines, having an authorized capital of over 800 millions, and upon which the gross annual receipts are 67 millions, and the annual working expenditure 35 millions. These railways carry 623 millions of passengers annually, besides half a million of season-ticket holders, and 246 millions of tons of minerals and general merchandise. Nor is this surprising seeing that railways and commerce stimulate and react upon each other. Thus, for instance, the output of coal alone in this country, the bulk of which is carried by rail, now exceeds 156 millions of tons per annum, whereas in 1855 it was only 64 millions.

Europe and America are the only continents which can be said at present to be moderately well furnished with railways, harbors, and other works which have now become necessaries of a civilized community. Yet out of the 1,334 millions of inhabitants of the globe, Europe contains but 328 millions, and America only 100 millions, making together barely one-third of the world's population; whilst Asia contains 700 millions, or more than double the population of Europe. Africa contains 200 millions, and China alone contains 280 millions, or nearly as much as all Europe, and nearly three times the population of America. What a vast field, then, still lies dormant to engineering enterprise, and who in the present day would venture to fix a limit within which the energies of the rising engineer shall be fettered?

Every passing year widens the pathway by opening up new discoveries and new subjects for employment. Those, however, who seek to follow the profession in these days without careful preparation, combining with sound practical experience, the mathematical and scientific principles which lie at the root of all engineering, and without a study of what has already been achieved by others, and of new discoveries as they are developed, would soon be left behind in the race in which they had embarked.

Although not specially designed for the better education of the younger members of the profession, the delivery of a series of lectures on the varied applications of electricity, at extra meetings held specially for the purpose during the past year, cannot have failed very materially to promote that object. It has also introduced into the history of the institution a new and marked feature. The announcement of the names of the eminent men, who had kindly consented to deliver those lectures, was a sufficient guarantee of their intrinsic value and interest. They were enthusiastically welcomed, and attended by overflowing numbers. The advantages to be derived from them, like their subject, are unlimited by time or space, and this institution is deeply indebted to their authors.

The success which has attended them has induced the council to inaugurate a second series of six lectures, during the present session, on the subject of "Heat in its Mechanical Appliances."

At the commencement of 1882 Sir William Armstrong drew attention to the manner in which the science of the engineer is now invoked for the purposes of war, the issue of which, he considered, would in future be chiefly dependent upon the superiority of the mechanical resources displayed.

The vast engineering and commercial enterprises referred to by Mr. Brunlees result from the more happy condition of peace, and it is proposed this evening to dwell more especially on those engineering works which promote the health and comfort of the inhabitants of large cities, and by which human life may be preserved and prolonged, and to furnish data from which some estimate may be formed of the sanitary condition and municipal management of some of the largest cities.

Civilization induces people to congregate in the neighborhood of cities and towns, for by daily intercourse, commerce, wealth, and intellectual development are encouraged. The geographical limits within which they can be brought into daily communication with each other have been enlarged by the introduction of railways, tramways, and other means of cheap and quick transit. But the rapid growth of cities constitutes the great difficulty of adequately providing for the requirements of the inhabitants.

Few, if any, cities, nor even docks,

railways, or other engineering works have originally been laid out with sufficient regard to the probable demands of the future. It is difficult to induce the present generation to expend its capital in providing for the requirements of after generations. The thoroughfares, sewers, and water supply, constructed for a city containing a few thousands of inhabitants, become totally inadequate to the wants of a population which has grown into millions; and the difficulties and costs of providing open spaces or widening thoroughfares in after years are very seriously increased. Thus, for instance, the first cost of forming a road which has subsequently become one of the main streets of a city was probably covered by the purchase of some vacant land and the structural works. But when in after years the road has become a crowded street, and costly buildings have been erected, and leases and trade interests of great value have grown up, the cost of their purchase becomes so great that not unfrequently the improvement is delayed, or its dimensions are cramped for want of funds.

London affords such an instance of rapid growth. It is now without a rival as regards its size and population, not only in the present, but as far as we know in the past history of the world. Our data as regards the past are very imperfect; but the population of Carthage, during the height of its prosperity, and shortly before its destruction, and the population of Rome about 300 years B.C., have each been estimated at about three quarters of a million, whilst that of Babylon was probably even less.

In defining its limits, London has been divided into what has been termed Outer London and London; Outer London, including several populous suburbs and the area over which the jurisdiction of the metropolitan police and some other metropolitan enactments extend, and London proper, which forms the subject of our more immediate consideration this evening, being limited by the municipal boundaries and under municipal government.

London, or the metropolis, as defined by the Metropolis Management Act of 1855, contains at present nearly 4,000,000 of people, covering an area of 117 square miles, upon which are built 500,000 houses, giving an average of eight persons to each house, and nearly seven houses and 53 persons to each acre. Its population is equal to that of the whole State of Holland, is greater than that of Scotland, and double that of Denmark, and if it continues to increase at the same rate until the end of the century, it will then equal that of Ireland, as indeed Outer London now does.

Its population has quadrupled since 1801, when it numbered only 959,000. From that date the increase has been at the rate of from 16 to 20 per cent. every ten years, estimated upon the population at the end of the previous decade.

It now increases at the rate of about 70,000 per annum, and when it is remembered that this is equivalent to the addition to London every year of the whole of the population of another city as large as Geneva or of Plymouth, one is inclined to ask in astonishment, Where will it end?

The value of property in London has increased even more rapidly than its population. In 1841 its rateable value was 6 millions sterling, in 1855 it was 10½ millions, and now it is 28 millions, having increased nearly five-fold in the last 43 years.

But the traffic through London has increased even more rapidly than either its population or rateable value. The arterial lines of thoroughfare, which were wide enough half a century ago, are now altogether insufficient. Thus, for instance, although the Strand and Cheapside have been relieved by the formation of a new route between Charing Cross and the Bank, along the Victoria Embankment and Queen Victoria Street, and Holborn has been relieved by a new route from Oxford Street to Shoreditch, and new and widened streets continued to be made throughout the city and other crowded localities, the old lines of thoroughfare still remain congested by the traffic. 384,000 pedestrians and 75,000 vehicles now pass over the metropolitan bridges daily; and the number of pedestrians increases at the rate of 4½ per cent. per annum, whilst the vehicles have increased at the rate of 13 per cent. The traffic on three metropolitan railways, viz., the Metropolitan, the Metropolitan District, and the North London, together increased between 1871 and 1881 from 79

millions to 136 millions per annum, or to 373,000 passengers per diem.

The government of the ancient City of London, by its Lord Mayor and Corporation, has up to the present time remained intact, with all its privileges and wealth; excepting that as part of the general municipality it sends three members to the Metropolitan Board of Works.

But the metropolis has from time to time been placed under the management of various local authorities. Prior to 1848 there were seven independent commissions of sewers. These were then consolidated into one commission. In 1855 the principle of local self-government was adopted, and 38 vestries, or district boards, subject to some general control of the Metropolitan Board of Works, were substituted, being representative bodies. The Metropolitan Board was also clothed with additional powers and duties, and these have in almost every subsequent year been enlarged, until it has now become the administrative authority for over one hundred Acts of Parliament affecting the metropolis. The present Government, however, have contemplated the creation of a new municipality, which shall include the city, and govern all the interests of the metropolis as a whole.

The demands for improvements of the metropolis, involving large expenditure, are still very pressing, for although the population in 1855 was more than two and a-half times greater than at the beginning of the century, little had been done up to that period in forming new, or widening existing thoroughfares, in sewerage, or other metropolitan improvements; and the onus has therefore been cast upon the present generation, not only of providing for the demands of their own rapid growth, but also for the growth of the previous half century; and, although 33 millions have been expended by the metropolitan authorities on such improvements since 1855, the arrears of the years of previous inaction are still far from having been wiped out, whilst the growth of each year brings with it fresh and irresistible demands for further expenditure. Hitherto the coal dues, which touch but slightly the pockets of the poor, and lighten the burden of municipal taxation to the extent of 2½d. in the pound, have stimulated the introduction of many of those improvements upon which we now look with satisfaction; and should those dues be allowed to expire, it will doubtless act as a damper upon the execution of works of urgent and growing necessity.

In 1878 there were 1,710 miles of streets, roads and courts, 1,338 miles of which were macadamized, or flint roads of an average width of 30 feet between the channeling, and upon which was laid in the course of the year 307,700 tons of macadam, flint or hoggin; 274 miles were granite-paved roads, and 61 miles were paved courts, 15 miles wood paving, and 22 miles asphalte; but since that period wood paving has been extensively substituted for some of the other kinds.

From the surface of those roads were removed in 1878, by scavenging, 616,500 cubic yards of scrapings, about 40 per cent. of which consisted of road detritus, 40 per cent. of water, and 20 per cent. of garbage from markets and refuse from the houses and streets. Upon the sides of the roads are fixed 67,500 catch-pits, from which also were removed 133,000 cubic yards, and about 25,600 cubic yards from the sewers.

Subways have been constructed under the Victoria Embankment, Queen Victoria Street, Garrick Street, Southwark Street, Commercial Street, and Northumberland Avenue, in which are laid gas and water mains and telegraph wires, in order to prevent the breaking up of the pavements of the streets.

There are now about 2,300 miles of underground covered sewers, more than half of which have been constructed during the last twenty-seven years. They vary in size from 9 inches to 12 feet 6 inches in diameter. All the houses are connected with them, and the house refuse and the most offensive decomposing matter is removed through them by the water supplied to the houses flowing through the sewers after use, in an unobtrusive, inoffensive, and economical manner, and without manipulation of any kind. The waste water thus becomes the motive power or carrier for conveying the refuse to covered reservoirs on the banks of the Thames 12 miles below London Bridge. These reservoirs are 16 acres in extent, and capable of containing 60 millions of gallons; and an aver-

age of about 150 millions of gallons of sewage and rainfall are discharged at the outfalls into the river daily on the ebb tides.

There are also forty-eight outlets at various points for the overflow of storm water into the river during heavy rains. Engines of 3,520 nominal HP. are employed at the pumping stations, which lift the sewage of the lower districts to heights varying from 18 to 36 feet.

The main intercepting scheme was practically completed and came into operation in 1870–71; and, considering that the mean annual death rate in London was, in the decade ending 1850, 24.8 per 1,000; in that ending 1860, 23.7; in that ending 1870, 24.4, and in that ending 1880 it had been reduced to 22.5, and for the year ending 1882 was only 21.4, it may not be unfair to claim for those works a considerable share in this decrease of the deaths. But a decrease from 24.4 to 21.4, or three persons per thousand, represents about twelve thousand lives saved every year in London, and a proportionate increased length of life to the living. The death rate for the past year has not yet been published, but it will probably be found to be about 1 per 1,000 lower than in 1882, so that the improvement since 1870 has been continuous, and the annual saving of life now, as compared with 1870, is about 16,000.

London is at present supplied with water by eight independent water companies, under the authorities and restraints of certain Acts of Parliament. They supply in the aggregate 140 millions of gallons daily, of which from 15 to 18 millions are consumed outside the metropolitan boundaries. The consumption within the metropolis is at the rate of about 31 gallons per head per diem. Of the total quantity 69 millions of gallons are obtained from the Thames, and 71 millions from the River Lee, the New River, and other sources. One hundred and forty-three pumping engines, of 16,490 nominal H.P., are employed, the head of pressure on the district supplied varying from 20 to 380 feet. They have ninety-three filter-beds, covering 95 acres; 54 subsiding reservoirs, covering 465 acres, and capable of containing 1,290 millions of gallons; also forty-nine service reservoirs, the capacity of which is 154½ millions of gallons, and 4,000 miles of mains laid, of which 3,000 are within the metropolis.

The charges of the water companies for the water are, with minor exceptions, based upon the rateable value of the houses supplied, and not according to the quantity of water consumed; that is to say, by their Acts of 1852, the Chelsea, the Grand Junction, the New River, and the West Middlesex Water Companies are authorized to charge 4 per cent. on houses rated under £200; and three per cent. on houses rated over £200; and the East London, and the Southwark andVauxhall to charge 5 per cent. on the rateable value of all houses; whilst the Lambeth, by their Act of 1848, may charge water rates varying from 7½ per cent in small houses to 5½ per cent. on houses rated over £100; and the Kent Company, by their Act of 1864, may charge from 6 per cent. on small houses to 4 per cent. on houses rated at £90 and upwards; and all the companies are authorized to make additional charges, fixed according to rateable value, for baths and water-closets, and in some cases for high service. But inasmuch as the rateable value of the houses in London has risen since 1855 from £4 per head to £7 per head of the population, and the consumption of water per head has remained the same, the price of water, as based upon the rateable value, is now 75 per cent. dearer than it was in 1855; and there is no reason to doubt that so long as the price remains a fixed charge upon the rateable value of the houses, the cost of each gallon of water consumed, and the value of the property of the water companies, will continue to increase in every future year in the like ratio.

The total capital employed by the water companies is about £13,200.000, or at the rate of 61.7d. per 1,000 gallons of water supplied, and the net income for water amounts to 7.3d. per 1,000 gallons; whilst the annual cost of pumping and maintenance of works is 1.1d., which, added to the cost of engineering and management, makes the outlay 2.7d. per 1,000 gallons, showing a net profit of 4.6d. per 1,000 gallons.

In 1880 it was proposed to purchase the interest and property of the water companies, and place the water supply under the municipal authority, as it is at

Glasgow, Manchester, Liverpool, and in most foreign cities; and an arbitrator between the Government and the water companies valued their interests at that time at £33,000,000.

The mode of charging upon the rateable value of the houses, instead of by meter, moreover, makes the payment for the quantity consumed fall very unequally upon the consumers. If charged by meter a very effective check would be put upon the serious waste which now takes place.

Five per cent. upon the present rateable value of £28,000,000 would produce £1,400,000 a year, which is about the income of the water companies for water supplied within the metropolis, and which is equivalent to 7.37d. per 1,000 gallons of water supplied, or at the rate of 7s. per head per annum, on the present average rate of consumption.

Four per cent. upon a house rated at £400 a year would make the water rate £16 per annum; whereas, if there were twelve inmates to such a house, charged according to the average consumption of water at 7s. per head, the water rate on that house would be only 4 guineas per annum.

But a house rated at £30 per annum, and charged 5 per cent. thereon for water, would pay, according to rateable value, £1 10s. per annum; and if it contained 6 inmates, and were charged according to quantity consumed, it would amount to £2 2s. per annum, supposing the quantity consumed were equal amongst all classes; but inasmuch as the poor do not consume so much water as the rich, these figures are only illustrative and approximately correct.

A purer and more copious supply of water, on constant supply and at high pressure, is demanded, and whether this is to be attained by purchase, or by some regulation of the present water companies' powers, it is obvious that each year's delay will only increase the cost and the difficulties involved.

The lighting of the metropolis is effected mainly by three gas companies, at a cost varying from 2s. 10d. to 3s. 2d. per thousand cubic feet. Over 20,000 millions of cubic feet of gas per annum are manufactured out of 2 millions of tons of coal, and it is distributed through pipes, the total length of which is about 2,500 miles; and they vary from 3 inches to 4 feet in diameter. The cost of lighting London by gas is therefore about £3,000,000 per annum, or more than double the cost of its water supply. The quality of the gas is tested by gas examiners at thirteen different stations, and is required to have an illuminating power of 16 candles when consumed at the rate of 5 cubic feet per hour, to be entirely free from sulphuretted hydrogen, with a maximum of 4 grains of ammonia, and from 17 to 22 grains of sulphur in 100 cubic feet of gas. In 1880 85,300 meters were tested.

But electric lighting is rapidly advancing; and, in confirmation of Dr. Hopkinson's opinion, that it may be looked upon as the lighting of the future, it may be mentioned that when, in 1878, the Jablochkoff Company commenced lighting a portion of the Victoria Embankment, the charge for each lamp was 5d. per hour. At the end of three months the price was reduced to 3d. Six months later it was reduced to 2½d., and, since June, 1881, forty lights on the Embankment and ten on Waterloo Bridge have continued to be lighted at the rate of 1½d. per light per hour.

Each of the electric lamps on the Embankment gives an illuminating power of 265 candles, so that, at the charge of 1½d. per hour per lamp, the cost per thousand candle power is 5.66d. per hour; whilst gas, at 3s. per 1,000 cubic feet, and consuming 5 cubic feet per hour for every 16 candles, costs per 1,000 candle power 11.25d. per hour. In other words, twice the illuminating power is at present obtained on the Embankment by electric lighting for the same money, if expended on gas. But it has been stated that the Jablochkoff Company are losing money on this contract. Incandescent lighting though much more costly in production, is more economical in the regulation and distribution of the light.

Eleven of the bridges over the Thames, on which tolls were levied, have been purchased and made free of toll within the last five years. At Hammersmith, Putney, and Deptford Creek new bridges are in process of construction. A new bridge at Battersea will shortly be built, and others have been strengthened with new chains or deeper foundations. But, considering that over 1½ millions of

people live east of London Bridge, that is to say, a greater population than exists in any city in the world, except London and Paris, it cannot be doubted that there is still a great need of improved communication across the river below London Bridge.

The Victoria, the Albert, and the Chelsea Embankments of the Thames are a total length of about 3 miles, and by them 52½ acres of mud foreshore have been reclaimed from the river and converted into thoroughfares and ornamental gardens.

Since 1865 the extinction of fires and the saving of life and property from fire has been a duty cast upon the municipality, and a brigade is maintained, under the direction of Captain Shaw, containing 54 land-engine stations, 4 floating engines, 124 fire escape stations, 576 firemen, 41 steam and 115 manual fire engines, besides tugs and other appliances. There were, in 1882, 1,926 fires, of which only 164 resulted in serious damage, and only 36 persons lost their lives, owing to the able management and gallant conduct of that small staff. The consumption of water in extinguishing fires is about 17 millions of gallons, and the cost of the brigade is rather over £100,000 a-year.

The Metropolitan Police outside the city are under the supervision of commissioners appointed by the Government; but the corporation of the city appoints its own police. They number in all 13,000; the area protected by them extends over Outer London, and covers 700 square miles, and the proportion of police to the population is rather less than in Paris, which is 1 in 373. But the area over which the Metropolitan Police are scattered is 23 times larger than in Paris, and it is satisfactory to know that, in spite of the amount of crime which escapes detection and punishment, London is the safest capital for life and property in the world. There are in London about 10,000 cabs, and 2,000 omnibuses or stage coaches under the management of the Metropolitan Police.

The parks, commons, and open spaces which are available for public recreation within the metropolis, and which form the lungs of London, are forty-two in number, and contain about 4,490 acres, exclusive of the squares, or about 6 per cent. of the whole area of London; whilst just outside the boundary are Epping Forest, Richmond Park, and Wimbledon Common, together containing 9,000 acres more.

There are fourteen markets of various kinds. The most important of these are: Farrington dead meat and poultry market, and Deptford Foreign Cattle Market; Islington Cattle Markets, 15 acres in extent; Billingsgate Fish Market and Covent Garden Vegetable Market; and into these markets are imported annually for consumption in London, about 800,000 head of cattle, 4,000,000 of sheep, calves and pigs, also 9,000,000 of fowls, game and rabbits, and over 100,000,000 of eggs, and a like number of oranges and lemons. About 320,000,000 of quartern loaves are consumed in London annually.

Billingsgate Fish Market covers only half an acre, and being insufficient for the supply of fish to the whole of London, a new market is contemplated. 35,000 vessels and 100,000 fishermen are employed in catching fish upon the coasts of the United Kingdom, and, besides the fish exported, 400,000 tons of fish are consumed in this country, of which 130,000 tons are sent to London, two-thirds by rail and one third by water. The average wholesale price of fish sold in Billingsgate is 1½d per lb., but the consumer does not get the benefit of this low rate, and to enable the poorer classes to enjoy the food which so abundantly surrounds our shores, a market is needed which shall be accessible to all railways, having the means of storing fish in dry air at a temperature of 34°, and accompanied by the means of rapid distribution to all parts of the metropolis.

Paris contains a population of 2,240,000, occupying 77,000 houses, and covering an area of 30 square miles. This gives an average of 29 persons per house, and four houses, and 116 persons per acre. Paris, therefore, is more than twice as densely peopled as London, and each house in Paris contains nearly four times as many inmates as the London houses. Its rateable value is twenty-four millions sterling, being not quite one-seventh less than that of London.

It has 582 miles of streets, upon which are laid 73½ miles of tramways, and the total length of its sewers is 440 miles.

Great care and labor are expended in cleansing and watering the streets and ornamental spaces in Paris. From a surface of over thirteen millions of square yards of street are removed annually 1,193,550 cubic yards of deposit, equal to a depth of 3½ inches of mud, dust and garbage spread over the whole surface. The cost of street cleansing in 1881 was £245,000, with a further expenditure of £82,000 for removing snow. The annual rainfall is 22 inches.

The water-supply amounts to eighty-two millions of gallons per diem, being at the rate of thirty-six gallons per head of the population. Two-thirds of this are obtained from the rivers Seine, Marne and Ourcq, and one-third from distant springs and artesian wells in Paris. Its sewers vary in size from 6 ft. 6 in. × 3ft. to 18 ft. 5 in. × 14 ft. 5 in., but the larger ones are in fact subways, containing galleries with a channel in the center, and waterpipes overhead. The construction of these has cost over four millions, and their cleansing and maintenance about £50,000 a year. A small portion of the sewage is disposed of by the irrigation of garden ground in the neighborhood of Paris, but by far the greater portion is still removed out of the city in cans by carts. In 1869 600,000 cubic yards were thus removed at an annual cost of about 2s. 3½d. per head of the population. There are four abattoirs under the administration of the municipality. Paris is lighted by gas lamps equivalent to 44,000 lamps of one burner each, which consume 770 millions of cubic feet of gas, at a cost for gas of £130,000, or about 3s. 4d. per 1,000 cubic feet, and a total cost of £190,000 per annum, including lighting and maintenance. This latter sum includes also the electric lighting of the Avenue de l'Opera, the Cours de Louvre and the Carousel; but this does not include the cost of lighting the private houses.

There are in Paris 600 omnibuses, 520 tramcars, 500 steamboats on the Seine, over 8,000 cabs, and the city is protected by a force of 6,000 men acting as police.

The city of New York contains a population of 1,350,000, occupying 100,000 houses, and averages 13.5 persons per house; and the population of Brooklyn is 585,229. New York has 350 miles of paved streets, through which are laid 200 miles of tramways, and 391 miles of sewers.

Its water-supply is derived mainly from the Croton River, and the supply amounts to 60½ gallons per head. Its annual rainfall is 46.68 inches; over a million of loads of refuse are removed from its streets per annum at a cost of £206,000.

Through the kindness of the British Consuls and other persons in authority I have been enabled to obtain, in a more or less complete form, some information with reference to 75 foreign cities. I do not propose to weary you this evening with all the data thus collected; but I have epitomized and tabulated it in a convenient form for reference, and it enables such a comparison to be drawn between some of the conditions existing in London and other large cities, as will justify the assertion that London is without a rival as regards health, extent and population. Next in importance to it is Paris, although it contains little more than half the population, and covers little more than one-fourth the area of London. The population of New York and Brooklyn together is nearly two millions, being rather less than that of Paris. Berlin, Philadelphia, St. Petersburg and Tokio (Japan), each contain about one million of people, and are equal to the joint population of Liverpool and Birmingham. Bombay, Vienna and Constantinople each contain about three quarters of a million: whilst Chicago, Pekin, Canton, Naples, Hamburg and Cairo, each contain about half a million, and are about the size of Glasgow. Calcutta, Baltimore, Boston, Buda Pesth, Madrid, Barcelona, Marseilles and Amsterdam, are about equal to Birmingham, each containing about 400,000; whilst the population of 40 of the remaining foreign cities varies from about 300,000 to 100,000, and they compare respectively with either Leeds, Hull or Brighton.

The rapidity with which the population of most of these cities has increased within the last forty years has been much greater than the rate of increase of the population of the globe. Thus, for instance, whilst the population of London, Paris, St. Petersburg and Vienna, has increased about 200 per cent., and that of Constantinople, Naples, Madrid, Rome and Amsterdam about 100 per cent., the population of the globe has increased

only 40 per cent., the greatest increase having been in America, and the least in Asia.

The rapid growth of cities is doubtless due to the development of civilization and of engineering science, which have stimulated manufactures and trade, and have turned those who were formerly agriculturalists into artisans, obtaining more lucrative employment in large cities. But these altered conditions demand commensurate civic improvements.

The ultimate object of all sanitary science is the comfort and convenience of the living, and the reduction of the death-rate; and although this will necessarily vary according to the climate and other local surroundings, in spite of all that human skill can accomplish, the death-rate may be largely reduced by the application of our improved knowledge of medical and sanitary science; and a reduced death-rate is therefore an indication of such advance. Thus, for instance, the death-rate of London has already been shown to have been gradually reduced from 24.4 per 1,000 in the decade ending 1870, to 21.4 per 1,000 at the end of 1882.

In Baltimore the death-rate is 21.9 per 1,000; in Boston, 22; Philadelphia, 22.3; Chicago, 23.6; Amsterdam, 24.3; Hamburg, 24.8; Rome, 26.1; Paris, 26.3; Berlin and Bombay, 26.4; Vienna, 29.2; Calcutta, 30.1; New York 30.6; Buda Pesth, 34.2; St Petersburg, 35.2; Cairo, 37; and in Pekin, though no accurate account has been kept, it is believed to be 50. These figures represent a saving of life in London which is worthy of special consideration; for whilst we indulge in a grumble at the atmosphere we breathe, at the water we drink, and the sanitary arrangements by which we are surrounded, London is, in fact, the most healthy city of magnitude in the world. If its death-rate were raised to that of Paris or New York, then from 20,000 to 36,000 persons who now live in London would die every year, or from 55 to 100 persons every day; and if the London death-rate were raised to that of St. Petersburg, then 55,000 more deaths would occur each year, or an average of 151 persons every day, in excess of the present deaths. Now it should be borne in mind that whilst the difference in the death-rate between London and Paris at the end of 1882 was 4.9 per 1,000, the average death-rate in England and Wales for the nineteen years between 1861 and 1880 was 21.9 per 1,000; and in France during the same period it was 23.7, being only 1.8 per 1,000 in excess of the death-rate in England and Wales, so that the improvement of the health of London cannot be attributed to its natural surroundings.

The comparative density of the population, and the number of persons residing in each house, vary very largely in different cities. In Chicago the average number of persons residing in each house is 4, in Baltimore and Naples 4½, in Philadelphia 6; in London, Boston and Cairo, 8; in Marseilles 9, in Pekin 10, in Calcutta and Amsterdam 11, in New York 13½, in Hamburg 17.07, in Rome and Munich 27, in Paris 29, in Buda Pesth 34.2, and Madrid 40; in St. Petersburgh 43.9; in Vienna 60½, and in Berlin 63.

The rateable value of the cities per inhabitant affords some indication of the cost, and therefore of the extent of accommodation of the houses, as compared with the number of their occupants; although the difference in the mode of rating, and in the cost of building, vary so greatly in different cities that this test cannot be altogether relied on.

In Pekin the rateable value of the city is £2 8s. per inhabitant; in St. Petersburg £1, Amsterdam £3 5s., and Calcutta it is £2 16s.; in Naples £3 12s., in Buda Pesth £4 4s., in Marseilles £5 2s., in Vienna £6 2s., in London £7, in Hamburg £7 9s., in Berlin £7 4s., Paris £10 14s., Brussels £11 8s.

The following tables give a comparative view of the quantities of water and gas supplied to the inhabitants of some of the most important cities in the world, the cost of providing the supply, the cost at which it is sold, and the margin of profit.

It remains to be determined whether a separate house for each family, however humble, or larger houses divided into separate flats for the accommodation of several families, is most conducive to health and comfort.

With larger houses divided into flats, it is practicable to give more air-space to each individual, to have wider streets, and at the same time to house a larger number of persons upon a smaller area.

Name of City.	Population.	Daily Water Supply.		Cost of Prouction per 1,000 Gallons.	Charge per 1,000 Gallons.	Profit per 1,000 Gallons.
		Total Gallons.	Gallons per Head.			
				d.	*d.*	*d.*
London.....	4,000,000	125,000,000	31.0	3.2	7.3	4.1
Paris	2,240,000	82,000,000	36.0	—	—	—
New York	1,350,000	79,152,389	60.5	—	—	—
Berlin	1,190,659	12,812,800	13.3	7.5	10.0	2½
Philadelphia	1,000,000	54,156,898	54.15	—	—	—
St. Petersburg.....	929,090	19,807,700	21.3	1.17	3.44	2.27

Name of City.	Population.	Annual Consumption of Gas.		Cost of Production per 1,000 Cubic Feet.	Charge per 1,000 Cubic Feet.		Profit per 1,000 Cubic Feet.
		Total Cubic Feet.	Cubic Feet per Head.		Public.	Private.	
London....	4,000,000	20,000,000,000	5,000	Net. 1/9½	3/1		1/3½ Mean 2/4
Paris.....	2,240,000	9,726,709,281	4,342	3/8 Deducting value of residual products, and including dues of all kinds paid to the municipality.	3/6	7/– Mean 6/	
Berlin.....	1,190,659	3,416,397,640	2,869	1/4 Including general expenses, but excluding rents, sinking fund, &c. 2/4 Including the latter items.	3/9	4/6* 4/3†	

* Supplied by Municipal Gas Works. † Supplied by Imperial Continental Gas Association.

When, therefore, it is stated that Paris, with more than half the population, covers only rather over a fourth of the area of London, and gives an average of 116 persons per acre, as against 53 persons per acre in London, it does not follow that Paris is therefore necessarily over-crowded. These conditions may exist with either superior or inferior house and street accommodation and sanitary appliances, and the expression "over-crowding" should have reference rather to an insufficient air-space per individual in the dwellings and the thoroughfares, than to the density of population per acre covered.

The condition of the few who can afford to live in well-built mansions, each as his separate castle, leaves but little to be desired; but for the masses of the population, who occupy smaller establishments, and more especially for the poorer classes, larger houses, laid out in separate tenements, appear to offer many advantages. The streets of a city in which such houses prevail will be shorter, and the cost of maintenance and cleansing therefore less, than when the population is spread in smaller dwellings over a greater surface. The working classes are, moreover, thus brought into closer contact with their employers than when

driven into poorer neighborhoods in the outskirts of a city, and at a distance from those business localities which afford them employment. Ground rents are reduced, the houses are more likely to be well built and to have their sanitary arrangements attended to, to have thicker walls and less exterior surface, as compared with the interior space, and therefore to be warmer and dryer. There has been of late years, and still is, a growing tendency in this direction in London, by the erection of such buildings as the Queen Anne's and Westminster Mansions, and many others at the West End for the rich, and the Peabody and other Artisans' dwellings for the poor.

In contemplating any comprehensive improvement or extension of large cities, the following are some of the questions which present themselves for consideration:

What should be the widths of the streets?

To what height should the houses be restricted?

What should be the minimum air-space allotted to each individual in the houses?

What proportion of the area of a city should be set apart for its lungs and recreation grounds?

What public buildings and markets, and what water-supply, sewerage, and means of lighting should be provided?

What should be the regulations to be enforced in order to secure the effectual combustion of fuel, and to prevent the contamination of the atmosphere by smoke?

The widths of the streets of a city should have reference, not only to the amount of traffic which may be expected to pass through them, but also to the heights of the houses surrounding them. When the houses are large and the population dense, the traffic in the streets will be greater, and, in order to secure the free admission of light and air, no street should be of less width than 40 feet, and not less than two-thirds of the height of the houses surrounding it.

The limit of the height to which houses may be carried with advantage is becoming extended by the more general use of hydraulic lifts, but it must have reference also, not only to the height at which the upper stories can be supplied with water, but also to the height to which a useful jet of water can be thrown in cases of fire, as well as to more general considerations of economy in construction and convenience.

The sizes and positions of the public buildings, markets, and open spaces for air and recreation, and the works necessary for water-supply and sewerage all require adaptation to the varying local conditions, and each will form the subject of special study for the engineer.

In London 5,800,000 tons of coal are consumed per annum, being at the rate of nearly 1½ ton per head of population, in addition to the 2,000,000 tons used in the manufacture of gas; and bearing in mind that each ton of coal consumed generates 56,000 cubic feet of carbonic acid gas, and that in a pure atmosphere there are not more than 3½ parts of carbonic acid to 10,000 parts of air, the mode of dealing with this product becomes a subject of grave importance. It is, however, the imperfect combustion of coal which causes the more apparent annoyance of smoke, soot and fog, and the appliances and regulations necessary to secure the effectual combustion of fuel, so as to prevent its waste and unnecessary contamination of the atmosphere, may be carried out in new cities without difficulty, and at no great cost. But there must always be great objection to the introduction into an old city of any improvement, however simple, which renders necessary some structural alteration in every house. Our past-president, Sir John Hawkshaw, recognizing this difficulty, has offered some valuable suggestions on the subject, advocating the more general use of semi-anthracite coal in the ordinary fire-grates in London.

Prior to the introduction of the Artisans' and Laborers' Dwellings Act of 1875, much had been done by private efforts to improve the dwellings of the poorer classes. No less than twenty-eight associations had been formed with this object, and had provided improved homes for thirty-two thousand four hundred and thirty-five persons, at a cost of about £1,200,000, and at an average rental per week of from 2s. to 2s. 9d. for one room, 3s. to 3s. 6d. for two rooms, and 4s. 6d. to 6s. 6d. for three rooms. The return realized upon the outlay varied from 2⅜ to 6¼ per cent. The average cost of eight blocks of build-

ings erected by the Metropolitan Association, including the purchase of land, or where leased, the ground rents, capitalized was at the average rate of £41 per inhabitant, varying from £29 to £81.

But these associations had the advantage of selecting such vacant sites as they could obtain on the most favorable terms, whilst under the operation of the Artisans' Dwellings Act the houses on any unhealthy district for which the new buildings are substituted must first be purchased compulsorily, as well as the public-houses and shops which are frequently mixed up with them, with all their trade interests, at a very heavy cost, and then cleared and new thoroughfares and sewers constructed.

Twelve areas, situate in different parts of London, embracing an aggregate area of 40 acres, in which the houses were overcrowded and declared to be unfit for human habitation, have been already dealt with by the Metropolitan Board of Works, at a cost of £1,500,000, and some further areas by the Corporation. In several areas the houses have been pulled down, new streets formed, and new buildings for the working classes erected on the sites, and in others the works are in various stages of progress. The cost of the new buildings has varied from 6d. to 8d. per cubic foot of the building, and the sites which have been cleared for their erection have been sold at prices ranging from 2s. to 5s. per foot super.

Inasmuch as the cost of a building depends mainly upon its size, it becomes necessary to consider what is the minimum air-space which can, with due regard to health, be allotted to each inmate. In the dormitories of poor houses and prisons a breathing space of from 450 to 500 cubic feet, with proper ventilation, has been deemed requisite for a healthy man; and two children have been estimated as equal to one adult.

The police requirements for the common lodging-houses are 240 cubic feet per head, and 450 cubic feet are allowed to each policeman lodged at a station. The Poor-law Board allowed 500 cubic feet per head in sick wards, and 300 feet for every healthy person in dormitories. Now 300 cubic feet per head means a room for two people, 8 feet high and $8\frac{3}{4}$ feet square, or for four people a room 8 feet high and $12\frac{1}{4}$ feet square; whilst 500 cubic feet per head means a room 8 feet high and $11\frac{1}{4}$ feet square for two people, and a room 8 feet high and $15\frac{3}{4}$ feet square for four adults. 500 cubic feet per inhabitant have been generally allowed in carrying out the provisions of the Artisans' Dwellings Act; and as the doors and windows of the new buildings are larger, and the surrounding streets and open spaces much wider than previously, the ventilation of the new buildings is superior to that of the old ones, and the condition of the atmosphere is thus rendered purer, although this air-space is less than could be desired.

Nevertheless, in comparing the death-rate, which has been below the average of that of the metropolis, in the new buildings, and the death-rate of the unhealthy localities for which they were substituted, it must not be forgotten that the comparisons refer to a totally different class of persons; all the habits of the persons displaced being eminently conducive to the shortening of life.

A practical difficulty is, morever, involved in every attempt to provide suitable houses compulsorily for the poorer classes, namely, that they object to be placed under any supervision or restraint, and cannot afford to pay the rents necessary to defray the cost at which the improved accommodation can be so provided, and even where low rents have offered it has been found that the new dwellings became inhabited by a better class than those who have been displaced from the unhealthy localities, and the occupants of these are driven into other poor neighborhoods which are thus again rendered overcrowded and unhealthy.

This, in fact, constitutes a great social dilemma, for whilst on the one hand the importance of suitable and healthy dwellings for the poor will be readily admitted, it may fairly be questioned whether it is just to throw the increased charge upon the rates, so that the man who is able only by industry and self-denial to pay his own rent, should be taxed for the rent of his less industrious and more self-indulgent neighbor; and why, he may fairly ask, if he is to pay a portion of his neighbor's house rent, should not the cost of his neighbor's food and clothing also be defrayed out of the public funds?

In order to be brought under the operation of the Artisans' Dwellings Act it be-

comes the interest of the landlord of the dwellings of the poor to allow them to fall into a condition which renders them unfit for human habitation, so that they may be purchased compulsorily, and the higher the rents the larger will be the amount of compensation he will obtain. It ought, on the contrary, to be made a disadvantage and loss to him to have his property declared unhealthy.

This property is frequently sublet to middlemen who collect such rents as produce a very high rate of interest on its value. What is needed is a more strict supervision by one competent authority, having no local interest, so that all places may be judged by a uniform standard. The provisions of the Common Lodging Houses Act, 1851, or of the Public Health Act of 1866, and the Artisans' Dwellings Acts of 1868, 1879 and 1882, might be modified, and the authority armed with more summary powers to oblige the landlords to repair and maintain their houses in a habitable and cleanly condition, and to prevent the demoralizing influence of overcrowding; and in cases of default, after due notice, such houses should be pulled down in the same manner in which "dangerous structures" are now dealt with under the Building Act of 1855. If the sites so cleared were sold for the erection of new dwellings for the poor, and money advanced for their erection at a low rate of interest, coupled with restrictions as to the class of building, and limiting the number of occupants, and the rents to be charged, the existing dwellings of the poor would be maintained in a proper manner, or new ones would be substituted at low rents.

The new dwellings would, nevertheless, become occupied by the laboring classes in receipt of regular wages, to whom, undoubtedly, a preference would be given; and the helpless and the depraved, who now seek shelter in overcrowded slums, would eventually be driven into the workhouses or common lodging-houses.

Longevity and premature decay are doubtless influenced by the food and general habits of the people, and by temperature and other local atmospheric conditions, although all these may be largely modified and brought under control by attention to sanitary laws and appliances. Artificial atmospheres are in fact created in large cities according to the character of the buildings, the airspace allotted in them to each inmate, and the mode of ventilation and warming, as well as by the width of the streets, the sewerage, and other sanitary arrangements. Moreover, the hereditary constitutions of the citizens become in after generations affected by the condition of the cities in which they and their forefathers have lived.

The facts and figures before us point to many of the causes for so great a variation in the death-rate as has been shown to exist in different cities. A high death-rate will, in most cases, be found to be the companion of defective house accommodation, ventilation, water-supply, sewerage, or scavenging. Thus, for instance, St. Petersburg, with a population of nearly a million, and the high death-rate of 35.2 per 1,000, is without sewerage, and its water-supply is taken from the River Neva, more or less contaminated by percolation from the subsoil. Cairo, with a death-rate of 37 per 1,000, is supplied with water from the Nile, having no sewers, and the sewage filtering through the subsoil into the Nile above the water intake. Vienna, with a death-rate of 29.2 per 1,000, has an average of sixty people in each house, or twice as many as in Paris, whilst the rateable value of the houses in Vienna is only one-sixth more than of those in Paris. Pekin, with a death-rate of 50 per 1,000, is without proper sewerage, water-supply, street-cleansing, or other proper sanitary arrangements.

The subject thus briefly touched upon largely affects the life and well-being of mankind, and is sufficiently interesting to invite closer and more exhaustive investigation under every variety of circumstances. For those members of the institution who have made sanitary engineering the subject of their special study, a wide field is open which will well repay its cultivation. The data which I have collected would form a starting-point for any member who will undertake the preparation of a paper for the institution. The Institution of Civil Engineers is the acknowledged representative head of our profession in all parts of the world. To be admitted to full membership has always been the just ambition of the ris-

ing engineer, because it is a real guarantee of professional status and qualification. It has, moreover, proved itself invaluable as the channel of communicating professional information, and of bringing its members into contact with each other, advancing their common interests, and encouraging good feeling.

It is the duty, and has always been the desire of its members, to embrace every opportunity to promote the objects of the institution. In doing this, the reputation of not a few has been first established through the ability displayed in the papers read, and in the discussions upon them at these meetings, all of which are widely circulated in the printed minutes. Allow me, in conclusion, to express an earnest hope that the meetings of the present session may be as productive of, at least, as valuable papers, and as good attendances and discussions as have characterized those of previous years.

THE TEST AND CHOICE OF LUBRICANTS BASED UPON A MECHANICAL METHOD OF TESTING.

By R. JAHNS.

From "Organ für die Fortschritte des Eisenbahnwesens," Abstracts of the Institution of Civil Engineers.

In testing a lubricant the two following conditions should be fulfilled:—

(1.) That the particular lubricant possesses those qualities necessary to reduce the friction, between two metal surfaces, to a sufficient degree for the purpose required.

(2.) That the particular lubricant has the power to resist, for a sufficient period of time, the destructive action of the work which it has to perform in its application.

Under the term "work" which the lubricant has to perform in the last condition, is understood the overcoming of the resistance of cohesion in the layer of lubricant between the two metal surfaces. This work not only produces heat, but also changes the chemical affinity of the constituents of the lubricant, and destroys and produces changes in their physical properties. The lubricant between the two metal surfaces is subject to no other action than this, and it must therefore appear advisable to base the test of the powers of resistance or endurance upon the examination of this action. Mechanical means must be preferred to the chemical tests generally employed, because the results of the former discover the effect of the action of all that takes place in the lubricant, which could not be perceived or followed by the chemical method alone. The author remarks that lubricants are still, in very many cases, solely judged and compared by their behavior in practice, and that this method only gives results, after a period of weeks or months, which are not even then reliable, as a regular and complete inspection cannot continually be made of the subjects of the test, whilst other factors, such as heat, cold, and dust, come into play. In the mechanical method these factors disappear, and the results of the test can be rapidly arrived at. For this purpose the test should deal with a minimum quantity of the lubricant, and the testing machine be constructed with this object in view.

To discover whether the first condition be fulfilled, the lubricant to be tested is applied to the outer surface of a hollow spindle and to the inner surface of a steel bearing, whose cross-section being a semicircle of a greater radius than that of the spindle immediately below it, the contact between the two metal surfaces is reduced to a minimum. Round the bearing, and attached to it, is hung a metal stirrup.

On the spindle being rotated, the perpendicular, passing through the centre of gravity of the stirrup and that of the cross-section of the spindle, is inclined at an angle from its original direction when at rest. This angle is directly proportional to the intensity of friction between the spindle and bearing with lubricant between them, and can be measured by a

scale on the lower portion of the stirrup. In testing to see how far the lubricant satisfies the second condition, that is, what amount of heat it develops in a given time, a testing-machine of the following construction is used.

To produce a satisfactory test, the heat generated must be solely derived from the lubricant. To this end a spindle, whose central portion is parabolic, is employed; on the top of this the segment of a bearing is accurately fitted, and held down by a weighted lever attached to the mountings of the machine. The spindle is supported below by two mounted rollers with flanges to their ends. A certain quantity of the lubricant to be tested is now poured upon the parabolic portion of the spindle, over which it is equally distributed by a strip of leather between the rollers and the spindle being moved to and fro by an oblique ridge on one of the rollers.

The spindle, which is hollow and closed at one end by a thin corrugated steel plate hermetically sealed, is now filled with sulphuric ether fumes, whose average expansion, within the limits of temperature occurring here, is about ten times that of the atmosphere.

On the spindle being caused to revolve by means of a belt passing round its centre, the heat given off by the lubricant is imparted through the metal of the spindle to the ether fumes within; these expanding, exert a pressure on the yielding corrugated plate, and set in motion the pricker, to which it is attached by an arm. Below this pricker is an endless sheet of paper stretched round two revolving cylinders, whose axes are parallel to that of the spindle from which motion is transmitted to them by a screw and wheels. A certain number of revolutions of the spindle is thus represented by a corresponding length of paper; the proportion in this case being chosen so that two hundred and fifty revolutions of the spindle per minute move the paper 3.75 millimetres (0.15 inches).

To avoid any hindrance to the progressive motion of the pricker mechanism is employed, by means of which the paper, at the end of every fifteenth second, presses against the pricker, releasing it again immediately.

The curve thus traced, after at first rapidly rising, soon becomes a straight line parallel to the direction in which the paper moves; after a time, if the lubricant be not renewed, its power will be exhausted, the temperature of the spindle increased, and the curve consequently again rise.

The abscissa of the curve represents the number of revolutions of the spindle, whilst the change of condition of the lubricant is represented by the ordinates; the product of the two, that is, the area between the curve and its abscissa representing the destructive action of the work in the lubricant.

Thus the power of endurance of a lubricant is inversely proportional to the area enclosed by the curve and its abscissa after any given period of time.

The author then goes on to express the relative value of two lubricants in the contents of two parallelopipeds of equal base, whose volumes are respectively equal to the areas enclosed by the curve into the sines of the respective angles representing the values of the lubricants in the first case. It is recommended that tests be made of good lubricants, such as olive and rape-seed oils, and these used as standards with which to compare all other tests.

At a recent meeting of the Berlin Physical Society Prof. Neesen gave a short account of the contrivance by which in his lectures he measured the mutual attraction of two magnets by means of scales. In conclusion, he reported experiments instituted by him with a view to determining the influence of magnetization on electrical conducting power. In these experiments he had made use of a magnetic substance of high specific resistance, a solution of chloride of iron. Two equal tubes were filled with the same solution, and inserted as the two branches of Wheatstone bridge into the circuit of a galvanic battery; the two other branches being so arranged that the galvanometer stood at zero. The electrodes in the two tubes consisted of iron plates, and were exactly alike. The tubes, that is, the fluid conductors, had in the diffent experiments different shapes and different diameters. The contents of the one tube were then magnetized either by a magnetizing spiral or by a powerful electro-magnet, and the galvanometer was observed during this process of magnetization. The result of the experiments was in every case a negative one. Very slight deflexions were indeed observed in the galvanometer needle in the case of the experiments with the magnetizing spiral, but these proceeded from the slight heating of the fluid, an effect which, notwithstanding the solution of chloride of iron was surrounded by a casing circulating water, had not been wholly avoided.

THEATRE VENTILATION.*

By Mr. JOHN P. SEDDON, F.R.I.B.A.

From "The Building News."

In his introductory remarks, he urged that every cowl disfiguring our chimneys was an unnecessary evil, as a smoky room was caused generally by want of a proper supply of fresh air to the fire, or else by some wrong construction of the fireplace or flues. Great as was the evidence of neglect of ventilation in our houses, the condition of our theatres was even worse. Dr. Angus Smith, in his work on "Air and Rain," gave a tabular statement of analyses of air from various sources, and showed that some samples from the dress circles of theatres were even more foul and prejudicial to health than others collected from within street sewers. Many people, though enjoying dramatic representations, seldom went to a theatre, because, although not particularly de licte or fastidious, they invariably suffered afterwards from the effects of the bad and heated atmosphere in them, or from colds caught in consequence of the efforts made to escape from it during the intervals between the acts. Theatre audiences had to imbibe such a noxious compound of the products of gas burners and human lungs as often converted the comedy they went to see into veritable tragedy. There is (continued the lecturer) no great practical difficulty in providing our theatres with fresh, and extracting foul, air, except what arises from attempting half-measures only; and it has been in consequence of such half-measures that the failures made hitherto have occurred. What is wanted is simply a plentiful supply of fresh air forced into every part of the building of a theatre, and not into the auditorium only, together with the extraction of the foul air from the several parts where it collects. This, then, is the problem—one of paramount importance—the solution of which appears to be still waited for alike in private and public buildings. I propose now to consider it specially in its relation to theatres, than which there is probably no description of building more capable of being efficiently warmed and ventilated; while yet there is certainly none other that is so generally devoid of all rational provision for health and hygienic comfort. It is obviously opposed to the interests of the manager of a theatre to have his house ill ventilated, for the very fact of its being so is a most powerful, perhaps the most powerful, reason that so large a number of the population avoid theatres altogether. This deterrent is infinitely more potent and active than any conscientious scruples respecting the morality of the stage, and it alienates a much larger proportion of the public. Religious disapproval does indeed keep away some persons from the theatre, but their number is as nothing to that of those who absent themselves solely and purely on account of the intolerable stuffiness of the atmosphere therein, and the almost inevitable headache that follows an evening spent in the majority of theatres. On the contrary, a well-ventilated theatre means, *cæteris paribus*, a full house for most nights of the week. I have been told that a theatre at Manchester was some years ago notorious for the extremely defective state of the atmosphere within it for want of proper ventilation, and that it was, in consequence very generally avoided—one lessee after another failing. But at last a manager, more enterprising and more enlightened than his predecessors, hit the right nail upon the head. He not only took the theatre, but he thoroughly ventilated it, and in a few years he retired with a handsome fortune. To the managers of theatres, and especially those of the lyric stage, good ventilation is a matter of special importance, because it immensely improves the acoustic qualities of buildings. That annoying echo which muddles up the notes in tantalizing confusion is instantly removed as soon as a good system of ventilation is applied to a building. Then it is seriously to be remembered that few buildings in the present

* A lecture delivered at the Parkes Museum of Hygiene.

day are wholly disconnected from the street sewers, as their drain-pipes, in spite of traps, do form a means of connection therewith. Now, theatres being the most highly heated buildings of any, act the most powerfully as pumps to draw up the gases and vapors underground into their interior, with what results it is easier to imagine than describe. This is another cogent reason why greater care should be given to the ventilation of theatres than even to buildings generally. Now, if it be, as I have stated, not so extremely difficult to accomplish so desirable a purpose, why have almost all the efforts in that direction been otherwise than successful? The answer to this question I believe to be: Because those efforts have been generally confined merely to the extraction of the vitiated air by means of mechanical or automatic appliances, and that in scarcely a single instance has there been in addition any intelligent effort to introduce by the same means a sufficient amount of fresh air, constantly flowing in, in order to take the place of the vitiated air that has been sought to be extracted, and at such a regulated temperature as to be inoffensive, by reason of the absence of cold draughts impinging upon persons sitting near the inlets. In consequence of this oversight the utmost that they were able to effect, therefore, was to draw in cold fresh air from the various accidental or temporary opening chinks around doors and windows, down chimneys, &c., so creating draughts; or to drain towards the auditorium the still fouler and more vitiated air from other wholly unventilated parts of the building. The above remarks apply likewise to sunburners, and to the great gas chandeliers so much affected in the old theatres. These only succeed in heating and expanding the air, and expelling, *pro tanto*, the amount so expanded. Mechanical extractors, such as fans, cylinders, pumps, &c., do indeed extract a considerable quantity of air from the auditoriums to which they are applied, and anemometers in consequence register thousands of cubic feet of air removed per minute, to the satisfaction of the patentees of such appliances. But, however satisfactory these results may prove to those gentlemen, they are not equally so to the unfortunate occupants of dress circles, as the semi-exhausted condition of the atmosphere so produced there is more intolerable than a surfeit of even vitiated air would be; while to the stall-holders, blasts of the comparatively cold, but far more highly vitiated air, from the parts of the house behind the stage front, for which no attempt at ventilation is ever made, sweeping over the footlights and carrying the gaseous products with them, are even more offensive. Some persons imagine that because theatres are lofty buildings that, therefore, they must be airy as well as spacious; but no mistake can be more fatal for they only form vaster receptacles of foul air and are far less easily emptied of the same than buildings of more moderate height would be, unless a proper system of ventilation is applied to them. Even when inlets to admit fresh air are provided for auditoriums of theatres, they are ordinarily upon an altogether insufficient scale, and being situated, as, indeed, they should be in ordinary buildings, but not in a theatre, at a level above the heads of the audience, they fail, in consequence, of producing the expected effect, because there are no exhausting outlets at a lower level to induce a circulation of the fresh air. In the rooms of other buildings the fireplace is the principal outlet for vitiated air, and at a low level. It, therefore drains off the heavy carbonic acid which falls as it cools. But in a theatre there is generally no extracting outlet fixed at so low a level, and, therefore, the occupants of the pit and stalls are placed, as it were, in a bath of carbonic acid, which rises, as it accumulates until they are forced to breathe it, to their discomfort and deadly peril. The foregoing remarks apply principally to the auditoriums of theatres; but the importance of extending a proper system of ventilation to the entire structure must not be overlooked for an instant. The stage, the greenroom, the dressing rooms, the refreshment rooms, the property rooms, and all the other parts of a theatre in which the numerous employés are engaged, need, though they seldom receive, equal consideration in this respect. These subordinate parts in almost every theatre, as in Covent Garden, for instance, are in a far worse condition than those portions that are devoted to the public. The condition of the

dressing rooms, and passages and corridors leading to them, are almost invariably exceptionally frightful, for they are numerously occupied with quantities of gaslights continually burning in them; and there are seldom any or but few outlets provided for the vitiated air generated in them, and they have no inlets for the supply of fresh air. Under such circumstances how can actors perform their parts with alacrity? Languor, the precursor of disease, must sap their energy. Yet again, the lobbies, the halls, and corridors should be most plentifully supplied with fresh air regulated in temperature, whereas, as a rule, these parts of a theatre are absolutely neglected in this respect. Were these filled with an ample supply of warmed or cooled fresh air, they would become feeders for the remainder of the building, and the cold draughts now complained of in even the best ventilated theatres, which sweep into the auditorium as soon as any of its doors are opened, would be entirely obviated. But, it may be asked, how can the whole of the multifarious parts of such a building as that of a theatre be sufficiently ventilated and warmed, or cooled, as occasion may require? My reply is, as before: By avoiding the half-measures only, which alone hitherto seem to have been attempted in this country. The thorough principle I am laying down is but the same that is universally, and on the whole successfully, adopted in America. It is only in points of detail that it would seem that the methods adopted by our trans-Atlantic cousins need some modification, such, for instance, as taking care that the warmed air is not burnt, and by increasing the freshness and volume of the warm-air supply needed in winter, or of the cooled air desirable in summer. The great essential for theatre ventilation is, that the whole structure, from basement to roof, should be completely filled throughout, by mechanical means, with pure air, regulated in temperature as required. At the same time, although it is the inlets that primarily demand attention, mechanical means should also be used secondarily for the constant drawing off of vitiated air from the several places where it is apt to collect, such as the floors of the pit and stalls, under the galleries, upper and dress circles, over the footlights, &c. The opposite plan to the above—that, namely, of relying mainly upon the exhausting appliances, and leaving the fresh air to enter as it can, to supply the place of the air that has been extracted—is fraught with evil from its liability to produce draughts from the various points whence the semi-vacuum created can succeed in obtaining a supply, such, for instance, as temporarily open doors, and even from the chimneys, down which the smoke is actually drawn by this abnormal demand for air. Indeed this is one of the most fruitful causes of the smoky chimneys, which cowls are supposed to remedy. The system I have thus recommended, if fully carried out, will get over the difficulty of having to decide whether the inlets should be vertical or oblique—a question that could only arise when they are small and few, and when the air they admit is unregulated in temperature; or whether the breezes needed should be obtained by utilizing the mouths of all the cupids, angels, and gods and goddesses that a fertile invention of the decorator of a theatre may introduce; or whether the cornucopiæ and such-like gauds should be made hollow or not. Given power enough, which is easily obtainable, to flood the whole building with air tempered as required, and it will matter less as to the precise distribution of the inlets in the auditorium itself. There is one thing that will doubtless tend to render this problem of the ventilation of theatres, which has been found so difficult, easier to accomplish—I mean the introduction of electric lighting instead of by gas. This has already been done by the enterprising manager of the Savoy Theatre—I doubt not to his own material advantage, as well as to the comfort of his ever-crowded audiences. Freedom from draughts has not, however, yet been attained in the auditorium of this theatre. The refreshment rooms, however, though situate some twelve feet below the level of the street adjoining, are admirably ventilated, much in the way I have proposed, by the Æolus Waterspray and General Ventilating Company's appliances, and it would only seem to be necessary to adopt the same system generally throughout the building to insure a complete success. We cannot afford, however, to let this present generation pass away stifled and incommoded, while

electricians are perfecting their methods of lighting. Nor is it every theatre that has a spare acre or two, in the middle of London, alongside of it, for the accommodation of a puffing steam-engine to create the light, nor an untenanted embankment as a convenient neighborhood to put up with the noise of one. In the meantime the gaslights in theatres should, as far as possible, have their products of combustion conveyed outside the building without being allowed to mingle with and contaminate the atmosphere of the interior. Yet, notwithstanding this serious drawback of the ordinary gaslighting to contend with, we have scientific resources at command sufficient to enable us to overcome all the difficulties that at present retard the proper development of this essential of civilization—proper and adequate ventilation. Another advantage of this system I am advocating that depends upon an ample supply of air forced in, rather than upon means of extracting the vitiated air, is that all those ugly cowls, which you must have noticed are my special *betes noirs*, become needless. A tax ought to be put upon every such excrescence in proportion to its size and unsightliness. This tax should be quite prohibitive of all such monstrosities as those that disfigure the roof of St. James' Hall, and make London a laughingstock to foreigners, who pay a little more attention to the beauty and sky line of their streets than we do of ours. We should soon then see the last of those metal pipes which obtrude from our roofs, looking as if they had sore throats wrapped round with comfortless comforters, and which in pretty little models seem sometimes to extract air with marvelous ease, but which somehow always fail to do so when most needed, as, for instance, when there is no wind to blow, or when it may happen to blow a little too hard. The system is applicable at moderate cost to old theatres as well as to new ones; and, of course, it is our oldest theatres that stand most in need of being ventilated, since most of them are but death traps to all concerned with them—audience and actors, and supernumeraries. It would, perhaps, be invidious in me, who, as an architect, cannot have any interest whatever in any of the numerous patent and other inventions for ventilating appliances which are offered to the public, to specify which of them I should particularly recommend. Assuredly, the proper course for any one desiring to build a new theatre, or to improve an old one, is to consult some professional man whose business it is to consider scientifically all the conditions of the special case with which he has to deal. Managers of theatres are evidently learning wisely to take this course; and without doubt most of the recently-built theatres are vast improvements upon those that preceded them. This is certainly due to the great skill and care bestowed upon them by their respective architects. If no theatre is yet absolutely perfect in this matter of ventilation (and I do not know one that is) I shall be glad if any hints or suggestions of mine, with regard to the general principles that should be followed, be of use or assistance to any of my professional brethren in their future works; and my object in bringing forward this matter will have been attained. I am not able to speak much from personal experience as to the condition of theatres on the Continent in regard to their ventilation. But I think it may be assumed that the general experience there is much on a par with that here. In the *Builder* for Sept. 22nd, 1883, the following statement appeared: "As for the matter of ventilation, that also requires, in the interest of the public, most earnest consideration. There at least we have but little to learn from our Continental neighbors, who suffer in their theatres quite as much as we do in ours. The day that the last grand chandelier shall have disappeared from our theatres will be a memorable one in the history of the stage. Then, at length, a visit to the theatre will cease to be what it is, at present, too often proves—a singularly uncomfortable mode of enjoying one of the most instructive of all pleasurable relaxations." There is, however, in this museum an example of French ingenuity devoted to the endeavor to remedy the state of things I have been describing. This is an elaborate design setting forth a scheme for a system of ventilation applicable to a theatre. It undoubtedly shows a considerable amount of cleverness and thought, and the disposition of the extracting flues, applied to the level of the floor of the pit and stalls, is admirable. But the author has certainly not to my mind grasped the

general principles that I have been endeavoring to prove to be the right ones. This may be seen from the very title that has been adopted—namely: "Ventilation des theatres: Injection, centrale, gratuité, Evacuation peripheric." That is to say, the admission of the fresh air is to be concentrated in the auditorium and is to be attained by what is called natural (as opposed to mechanical) means, to supply the place of the vitiated air to be extracted by flues placed round that part of the theatre, no other than which has ever been considered. The author, a Parisian architect, commences by saying that "no place is more easy to ventilate than a theatre"; which renders me curious to know if he has ever reduced his theories to practice, because I should anticipate that he would simply have succeeded in making the building a veritable "temple of the winds." The reason, however, that he gives for considering that this class of structure is easy to ventilate is, "that the people in it occupy fixed places in the circumference, leaving the whole central part empty." From which remark it is obvious that he ignores the remainder of the building with all its exceedingly complicated arrangements, and the numerous parts where foul air can and does collect, and thence invade the auditorium. "The injection of the fresh air," he continues, "is easily obtained gratuitously." That is, it is suffered to come in at its own good will and pleasure, if it will do so, to replace what is drawn off by the exhausting appliances. I have, however, already explained what the result of such an experiment would be. "This injection of fresh air," he says, "being made far enough from the spectators, so that none of them are inconvenienced by it; it is also made under such conditions as to make the transmission of the sound-waves from the scene to the public." Now, the position he has chosen for this concentrated inlet of air is at the back of the stage, facing the auditorium, whence it would rush, charged with all the dust raised by the motion of the actors on the stage and by the shiftings of the scenes, over the footlights right into the faces of the stallholders. We may, I think, turn with greater advantage to consider the attempts that have been made in America, where necessarily, from its climatic extremes, the subject of ventilation has been much considered. The following particulars I have just met with (after the foregoing remarks had been written) in a paper, by Mr. Arthur J. Gale, upon "American Architecture," published in the *Transactions* of the Royal Institute of British Architects for 1882–84. These seem to show that ventilation upon (as far as I can judge) the identical principles I have laid down, has been successfully carried out in the Madison Square Theatre in New York. Mr. Gale says that this is not a very large but a very successful house. He then describes it as follows: "The fresh air inlet is by a descending flue, 6ft. square, lined with wood, in which is a conical cloth bag 40 ft. deep, to filter the air, which afterwards passes over ice in summer, four tons being used each night—two tons before and two tons after the air passes the fan at the bottom of the inlet shaft. This fan forces the air into a brick duct, from which sheet-iron pipes lead it into four brick casings surrounding steam radiators that supply the required heat in winter. This fresh air, so regulated in temperature, is conveyed by 4in. tin circular pipes to the four sections of 90 seats each in the auditorium. Other special ducts supply additional cooled air, when needed, to other parts of the building. All the gaslights are incased in glass, and have ventilating shafts. By these and other exhaust shafts the vitiated air is drawn off from various parts of the building by means of another fan in the roof. The footlights are ventilated by the same means. Tests have proved the ease with which the system can be worked and the excellent results which have been attained by it. The temperature on one occasion at 9.30 P. M. was outside 85 degrees Fahrenheit in the delivery, just beyond the ice 70 degrees, and at the main outlet 86 degrees. I really think now that, having cited the last two examples, the one showing, as I think, how not to ventilate a theatre, and the other being a record as to the manner in which one has been successfully treated, I need say no more in support of the general principles that I have advocated. As to the special appliances which are required to carry them out in practice, they must necessarily vary according to circumstances. I shall conclude, therefore, with the recommendation to managers to give the

system proposed a fair trial, and not to be content with half-measures, and, as a parting piece of advice to be cautious not to allow themselves to be led, or misled, as in all probability they would be, by the specious advertisements of patentees of particular appliances, the value of which (if any) depends entirely upon the manner in which they are employed. In all cases they would be wiser to place this class of work in the hands of a professional architect in whom they have confidence, and whose reputation would depend upon the success of the result as a whole, and who, of course, has no interest whatever in anything that would form part of the details of the general arrangement. Since the foregoing paper was written, my attention has been called to a description of the ventilation and warming of the Metropolitan Opera House of New York, given in the *Sanitary Engineer* paper of that city, for December 20th of last year. The system adopted seems to be exactly what I have recommended, and to have been designed and carried out by the architect, Mr. J. Cleveland Cady, and the ventilating engineer, Mr. Fredric Tudor. The principle involved is stated to be that of "plenum ventilation," the object being to have an excess of air entering the building to that which is leaving it by the regularly provided foul-air outlets, the result of which is to have a pressure within the building slightly in excess of that of the air without the walls, so as to insure an outward current through crevices of doors and windows, or accidental openings. To accomplish this in a practical manner a blowing-engine is used, and the supply of air almost unlimited. The air is drawn in at a height of 75ft. from the ground, down a shaft to what is called a settling chamber, 48ft. by 20ft., by 10ft. high, whence it is drawn through heating coils by a fan to a main air-duct. The air is admitted to a space under the auditorium floor, through numerous openings, and thence through the risers of the steps on which the drains are set. The boxes are supplied from the main air-duct by flues in the walls leading to spaces between their floors and ceilings. By this means every stationary chair in the house has air admitted to it. Outlets for foul air are provided where the several gas-lights afford extracting power. There is a principal controlling valve to the ventilation in the center of the dome-shaped ceiling of the auditorium. By the adjustment of this the pressure within the house is regulated, and the condition of plenum maintained under varying conditions of the speed of the fan. The stage has separate ventilating and warming appliances, by means of which a difference of pressure is kept between the house and the stage when the curtain is down, enough to belly the latter slightly towards the stage; the rising of the curtain then allows air to pass from the house to the stage ventilators. I am told that the Criterion Theatre is constructed below the level of the street, and consequently a most difficult place to ventilate, and when first built almost insupportable from foul heated air; it was made pure and sweet, and the temperature kept down by a ventilator of the "Norton" system, which consists of an extracting appliance of great power without, however, provision for fresh air to replace that extracted, other than what might find its own way downward from the street. Unfortunately this ventilator has been removed to gain space in some recent alterations. In the Prince's Theatre, recently opened, and built by Mr. Phipps, as at the Savoy, the basement, the most difficult portion of a building to ventilate, has been most efficiently ventilated and warmed by the "Æolus Waterspray Company." The success attending this system thus partially employed renders it a matter of regret that it was not applied to the whole structure in the thorough manner I have advocated. Had it been so, I think we should have had as memorable an example of improvement to record as that at New York, which I have been describing. I think, at any rate, it is evident that this system affords ample power to completely warm and ventilate any building, and no doubt there are others that can accomplish the same end. It remains for architects, or rather their employers, to make proper use of the means now placed at their command. The comfort and health of the actors and *employes* at theatres would be very greatly enhanced if, in their dressing rooms, which as a rule are wholly neglected and in a parlous condition, the simple precaution were taken which should be adopted in the rooms of all buildings—

that, namely of providing a supply of fresh air to every fireplace, and extracting the foul air by ventilators into the smoke flues. There are numerous excellent appliances for this purpose, such as Boyd's, Shillito's, and other ventilating grates, now so constantly and properly employed in school buildings. In fact, every grate, stove, or other heating apparatus ought to be compelled to be made a place for the admission of fresh air, because it is easily tempered and admitted there without causing draughts. I consider that some public authority ought to condemn as uninhabitable every room to which fresh air is not thus supplied, and I am sure that by such a simple regulation the annual death-rate of the community would be at once greatly diminished. Smoky chimneys would become almost things of the past, and cowl manufacturers extinguished. If a chimney smokes, the last place that needs to be looked to is the top of the chimney; the first is the fireplace and its surroundings. A chimney smokes. Why? The room has no supply of air, or the fireplace has been badly constructed, leaving a reservoir of stagnant cold air above it; or the flue is too large, which is generally the case; or too straight, with no provision of expanded space for gusts of down draughts to expend themselves in; or lastly the top may be without any protection against wind or special currents of air. But whatever the cause, sufferers from smoky chimneys can, as a rule, conceive of no remedy but a cowl, whereas that is the last that should be tried. Take out and reset the grate, or replace it by one to which air can be freely admitted, or contract the opening above the fireplace, or make an expansion in the flue for down draughts to expend themselves in, or put a slightly architectural finish to the top of the chimney, to shield it from the wind which injuriously affects it. But do not put up an ugly twisted twirling corkscrew excrescence to distract your neighbors as well as yourself, to ruin the skyline of your buildings, and proclaim to all the world your misery and ignorance, as well as that of your architect and builder. There are in this museum and elsewhere many useful appliances for the construction of all the several parts of a building used in the consumption and extraction of smoke; but it seems to me evident from their comparative scarcity in houses generally, that the public does not realize their utility—I might even say their necessity. I think this arises from their being presented to their notice in what I may call a desultory and isolated manner. I have therefore arranged with a firm to show the proper construction of fireplaces with their flues and chimney tops as they ought to be built, at the forthcoming Health Exhibition, in a complete system. By this means the public, I think, will be able to see the nature of the general problem which has to be grasped, and then can judge which of the appliances exhibited in that exhibition are the most suitable for each special purpose. Otherwise they are likely to become bewildered among the multitude of articles presented to their notice, most of which, though good in themselves, are liable to fail unless combined and applied with intelligence.

MAINTENANCE AND ROLLING OF MACADAMISED ROADS.

By A. DEBAUVE.

nslated from "Annales des Ponts et Chaussées," for Abstracts of the Institution of Civil Engineers.

A DETAILED comparison is drawn between the relative advantages and disadvantages of the maintenance of roads in the country by patching and by rolled layers; and also between rolling with horses and by steam. The advantages of the system of repair by patching are, great simplicity, and a regular profile of road; the disadvantages are, loss of material, and injury to the traffic. The system of layers appears more costly in the first instance than patching; but the expenses of cleaning and sweeping, the crushing and shorter duration of the metalling, and the inconvenience and the harm done to the traffic in the latter case, more than balances this in the case of roads of any importance. The advantage

of layers over patching is greater in proportion to the cost of the road metal; and the only serious drawback to the system is that, towards the close of the life of a layer, the road, having become hollow in the centre, is liable to be rapidly deteriorated in a very rainy season.

After giving some information on the best thicknesses for layers of metalling, and the points to be attended to for securing a good road, the author proceeds to the consideration of horse and steam rollers. As the resistance to traction is much greater over a new layer at the commencement of the rolling than towards the end, whilst the number of horses harnessed to a roller remains the same, it is advantageous to be able to double the weight of a roller. The Moquet roller realizes this condition, having a weight of from about $3\frac{1}{2}$ to $4\frac{3}{4}$ tons when empty, which can be increased to from 7 to $7\frac{1}{2}$ tons by filling two large, deep cases with gravel. The balance is secured by placing one case in front, and one behind the roller; and the lowness of the centre of gravity gives great stability. It is important that the roller should turn easily, to avoid having to unharness the horses; and the system in which the roller is formed, of four similar rings side by side, accomplishes this. An index recording the number of revolutions, with which the steam rollers are provided, would be a very useful adjunct to horse rollers. The heaviest rollers are the best for rolling new layers of metalling; but the weight is practically limited to what six or seven horses can draw, the largest number which is readily procurable, and which can be easily managed; and about 7 to 8 tons is the heaviest roller they can draw properly. The cost of traction with horses on main roads, with gradients not exceeding 1 in 33, allowing a turn for every 220 yards, is about 3*s.* 6*d.* per mile, and about $13\frac{2}{3}$ miles are traversed in a day of ten hours.

Four steam-rollers were purchased, within the last three years, for forming and repairing several main roads in the department of Oise, as it was doubtful whether sufficient horses could be procured for rolling in the ordinary way. Each roller cost £480, and weighed from 10 tons to $11\frac{1}{4}$ tons, according to its load of water and coal. The minimum pressure exerted by the steam roller per foot of width is $1\frac{1}{2}$ ton, which is the same as that of the half-loaded horse roller, whose smaller width compensates for its lighter weight. Owing to the greater width of the steam roller, a day's journey of $8\frac{2}{3}$ miles with it is equivalent to the $13\frac{2}{3}$ miles of the horse roller, and this distance is easily accomplished by the steam roller, so that its effective work is at least equal to that of a horse roller with six or seven horses, on roads with moderate gradients. In the exceptional case of gradients from 1 in 33 to 1 in 20, the steam roller is much more advantageous. The cost of traction with the minimum of six horses, is 38*s.* 4*d.* per day; whilst with the steam roller it is as follows:

Driver	8.0
Coal, 3.2 cwt. at 32*s.* per ton	5.12
Oil, waste, wood, &c.	2.08
Allowance for cleaning and stoppages	2.0
Total per day	17.2

which is less than half the cost of traction with horses. The actual cost of traction with a steam roller, in the author's district, per cubic yard of material used for repair, during 1880–82, amounts to $8\frac{1}{2}d.$; whereas the mean cost in another district, with horse rollers, was 15*d.*, making a saving with steam rolling of $6\frac{1}{2}d.$ per cubic yard, or a total saving of £366 in two years. On this estimate, the cost of the steam roller would be saved in three years; and as, in the special work accomplished by the steam rollers, the cost with horse rollers would have really reached $25\frac{1}{2}d.$, instead of 15*d.*, the steam rollers have already effected a saving exceeding their cost. The possible objections to the use of steam rollers are shown to be immaterial; and the conclusion arrived at is, that steam rolling marks an important progress in the maintenance of ordinary roads.

M. Chevreul has probably enjoyed a longer working period than any other great scientific worker. About a month ago he communicated a paper to the Academie des Sciences, at the close of which he remarked: "The observation is not a new one to me; I had the honor to mention it here at the meeting on the 10th of May, 1812."

ON MORE CONVENIENT EQUIVALENTS FOR CONVERTING BRITISH INTO METRICAL MEASURES THAN THOSE HITHERTO IN USE.

By G. JOHNSTONE STONEY, D.Sc., F.R.S.

From "Nature."

Capt. Clarke's determination of the length of the British yard in metrical measure, made at Southampton in 1866 for the Ordnance Survey (see *Philosophical Transactions* for 1867), differs by a small amount from that which had been previously made by Capt. Kater, and it is noteworthy that the small difference between these excessively careful determinations is greater than the difference between Capt. Clarke's determination and the very simple equivalent,

The yard=914.4 millimeters;

so that the outstanding error which will be incurred if this very convenient number is adopted is of an amount which is inappreciable in ordinary good scientific work. It is less than the expansion produced in iron standards of length by one degree of temperature. Again, the pound avoirdupois differs, according to Prof. Miller's determination (which is the most elaborate we possess), from the simple equivalent,

The pound=453.6 grammes,

by only one-quarter of a grain avoirdupois in a kilogramme. This is about 1/70 of the correction which would have to be made in weighing water in order to reduce its apparent weight to its weight in vacuo, and is of small account even in carefully conducted scientific work. The value of the gallon, which follows from Capt. Clarke's determination of the meter, is 1.000027 times that adopted in Dowling's Metrical Tables, and differs from the simple equivalent,

The gallon=4544 cubic centimeters,

by an amount which is less than a cubic centimeter in ten liters, an error which is inappreciable; measures of capacity not admitting of being compared so closely as weights and measures of length. Hence we may take as our fundamental units—

The yard=914.4 millimeters,

with an error of less than a fifth-metret* in the meter, on the authority of Capt. Clarke;

The pound=453.6 grammes,

with an error of one-quarter of a grain avoirdupois in a kilogramme, on the authority of Prof. Miller;

The gallon=4544 cubic centimeters,

with an error of less than one cubic centimeter in ten liters, on the authority of the best previous determinations corrected by Capt. Clarke. It is a truly remarkable circumstance that the first of these numbers happens to be divisible by 3^3 and 2^3, the second by 2^3 and 7, and the third by 2^6. Divisors more convenient could hardly have been chosen for dealing with the disorderly way in which British measures are subdivided. They furnish the following tables, which may be safely recommended:

Table I.—Measures of Length.

The yard	= 914.4	millimeters.
The foot	= 304.8	"
The inch	= 25.4	"

Table II.—Weights.

The pound	= 453.6	grammes.
The half-pound	= 226.8	"
The quarter pound	= 113.4	"
The ounce	= 28.35	"
The grain	= .0648	"

[This last gives the gramme=15.43210 grains, a number which it is singularly easy to recollect.]

Table III.—Measures of Capacity.

The gallon	=4544	cubic centimeters.
The quart	=1136	"
The pint	= 568	"
The half-pint	= 284	"
The noggin	= 142	"
The fluid ounce	= 28.4	"

* By metrets are to be understood decimal subdivisions of the meter. The fifth-metret is the fifth of these, or the hundred-thousandth of a meter. It is about the diameter of one of the red disks in human blood.

If any person using these tables wishes to carry refinement farther, he may do so by subtracting one in every hundred thousand after using Table I, by subtracting one in sixty thousand after using Table II, and by subtracting one in ten thousand after using Table III. These corrections will carry accuracy to the limit of Prof. Miller's and Capt. Clarke's determinations.

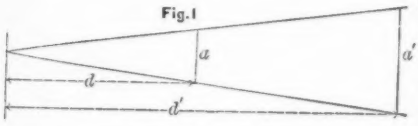
THE THEORY OF STADIA MEASUREMENTS ACCOMPANIED BY TABLES OF HORIZONTAL DISTANCES AND DIFFERENCES OF LEVEL FOR THE REDUCTION OF STADIA FIELD OBSERVATIONS.

By ARTHUR WINSLOW, Assistant Geologist, Second Geological Survey of Pennsylvania.

Contributed to VAN NOSTRAND'S ENGINEERING MAGAZINE.

THE fundamental principle upon which stadia measurements are based, is the geometrical one that the lengths of parallel lines subtending an angle are proportional to their distances from its apex. Thus if, in Fig. 1, a represents the

Fig. 1



length of a line subtending an angle at a distance d from its apex, and a' the length of line, parallel to and twice the length of a, subtending the same angle at a distance d' from its apex, then will d' equal $2d$.

This is, in a general way, the underlying principle of stadia work; the nature of the instruments used, however, introduces several modifications, and these will be best understood by a consideration of the conditions under which such measurements are generally made.

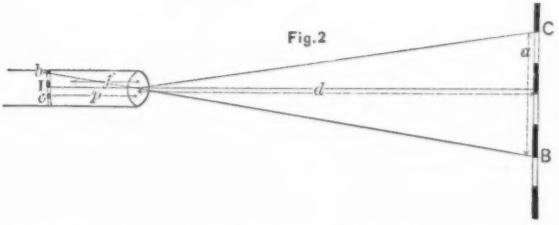
In the telescopes of most instruments fitted for stadia work, there are placed either two horizontal wires (usually adjustable) or a glass with two etched horizontal lines at the position of the cross wires, and equidistant from the center wire.

A self-reading stadia rod is further provided, graduated according to the units of measurement used.

In a horizontal sight with such a telescope and rod, the stadia wires seem to be projected upon the rod and to intercept a distance which in Fig. 2 is represented by a.

In point of fact there is formed, at the position of the stadia wires, a small conjugate image of the rod which the wires intersect at points b and c, which are respectively the foci of the points B and C on the rod. If, for simplicity's sake, the object glass be considered a simple bi-

Fig. 2



convex lens, then, by a principle of optics, the rays from any point of an object converge to a focus at such a position that a straight line, called a secondary axis, connecting the point with its image, passes through the *center* of the lens. This point of intersection of the secondary axes

is called the optical center. Hence, it follows that lines such as c C and b B, in Fig. 2, drawn from the stadia wires through the centre of the object glass will intersect the rod at points corresponding to those which the wires cut on the *image* of the rod. From this follows the proportion:

$$\frac{d}{p}=\frac{a}{I}\therefore d=\frac{p}{I}a, \quad . \quad . \quad . \quad (1)$$

Where:

d=the distance of the rod from the center of the objective;

p=the distance of the stadia wires from the center of the objective;

a=the distance intercepted on the rod by the stadia wires;

I = the distance of the stadia wires apart.

If p remained the same for all lengths of sight, then $\frac{p}{I}$ could be made a desirable constant and d would be directly proportional to a. Unfortunately, however, for the simplicity of such measurements, p (the focal length) varies with the length of the sight, increasing as the distance diminishes and *vice versa*. Thus the proportionality between d and a is variable.

The object, then, is to determine exactly what function a is of d and to express the relation in some convenient formula.

The general formula for bi-convex lenses is:

$$\frac{1}{p}+\frac{1}{p'}=\frac{1}{f}. \quad . \quad . \quad . \quad (2)$$

f is the *principal* focal length of the lens, and p and p' are the focal distances of image and object, and are *approximately* the same as p and d, respectively, in equation (1):

$$\text{therefore, } \frac{1}{p}+\frac{1}{d}=\frac{1}{f}, \text{ approximately.}$$

$$\text{and } \frac{d}{p}=\frac{d}{f}-1$$

$$\text{From (1), } \frac{d}{p}=\frac{a}{I}$$

$$\therefore \frac{a}{I}=\frac{d}{f}-1$$

$$\text{whence } d=\frac{f}{I}a+f \quad . \quad . \quad . \quad (3)$$

In this formula, it will be noticed that, as f and I remain constant for sights of all lengths, the factor by which a is to be multiplied is a constant, and that d is thus equal to a constant times the length of a, plus f. This formula would seem, then, to express the relation desired, and it is generally considered as the fundamental one for stadia measurements. As above stated, however, the equation

$$\frac{1}{p}+\frac{1}{d}=\frac{1}{f}$$

is only *approximately* true and the conjunction of this formula with (1) being, therefore, not rigidly admissible, equation (3) does not express the exact relation.* The equation expressing the true relation, however, though differing from (3) in value, agrees with it in form and also in that the expression corresponding to $\frac{f}{I}$ is a constant and that the amount to be added remains, practically, f. The constant corresponding to $\frac{f}{I}$ may be called k† and thus the distance of the rod from the objective of the telescope is seen to be equal to a constant times the reading on the rod, plus the principal focal length of the objective. To obtain the exact distance to the *center* of the instrument, it is further necessary to add the distance of the objective from that centre, to f; which sum may be called c. The final expression for the distance, with a horizontal sight, is then

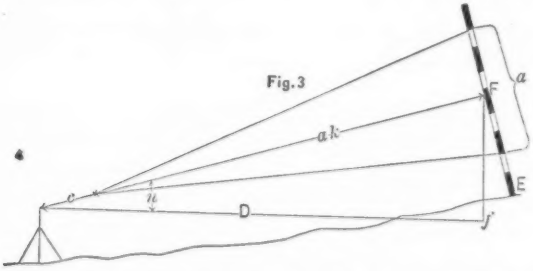
$$d=ka+c \quad . \quad . \quad (4)$$

The necessity of adding c is somewhat of an incumbrance. In the stadia work of the United States Government surveys an approximate method is adopted in which the total distance is read directly from the rod. For this method the rod is arbitrarily graduated, so that, at the distance of an average sight, the same number of units of the graduation are intercepted between the stadia wires on the rod, as units of length are con-

* This is demonstrated on page 318.

† k is dependent upon I and can, therefore, be made a convenient value in any instrument fitted with adjustable stadia wires. It is generally made equal to 100, so that a reading on the rod of 1 corresponds to a distance of 100+f.

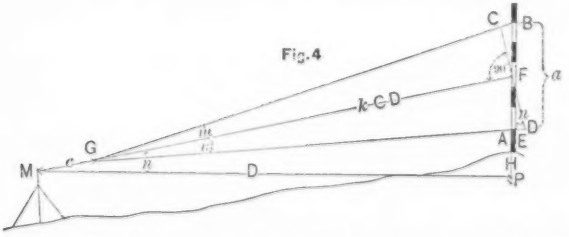
tained in the distance. For any other distance, however, this proportionality does not remain the same; for, according to the preceding demonstration, the reading on the rod is proportional to its distance, not from the center of the instrument, but from a point at a distance "c" in front of that center; so that, when the rod is moved from the position where the reading expresses the *exact* distance to a point, say half that distance from the instrument center, the reading expresses a distance *less* than half; and, at a point double that distance from the instrument center, the distance expressed by the reading is *more* than twice the distance. The error for all distances less than the average being minus, and for greater distances plus. The method is, however, a close approximation, and excellent results are obtained by its use.



ment was, however, bulky and difficult to construct, and never came into extensive use.

For stadia measurements with inclined sights there are two modes of procedure. One, is to hold the rod at right angles to the line of sight; the other, to hold it vertical. With the first method it will be seen by reference to Fig. 3, that the distance read is not to the foot of the rod E, but to a point, f, vertically under the point, F, cut by the center wire. A correction has, therefore, to be made for this. An objection to this method is the difficulty of holding the rod at the same time in a vertical plane and inclined at a definite angle. Further, as the rod changes its inclination with each new position of the transit, the vertical angles of back and foresight are not measured from the same point.

The method usually adopted is the second, where the rod is always held *vertical*. Here, owing to the oblique view of the rod, it is evident that the space intercepted by the wires on the rod varies, not only with the distance, but also with the angle of inclination of the sight. Hence, in order to obtain the true distance from station to station, and also its vertical and horizontal components, a correction must be made for this oblique view of the rod. In Fig. 4,



Another method of getting rid of the necessity of adding the constant was devised by *Mr. Porro*, a Piedmontese, who constructed an instrument in which there was such a combination of lenses in the objective, that the readings on the rod, for all lengths of sight, were exactly proportional to the distances.* The instru-

* A notice of this instrument will be found in an article by Mr. Benjamin Smith Lymon, entitled "Telescopic Measurements in Surveying," in *Jour. Franklin Inst.*, May and June, 1868, and a fuller description is contained in *Annales des Mines*, Vol. XVI, fourth series.

AB=a=the reading on the rod;

MF=d=the inclined distance=$c+$GF $=c+k$CD,

MP=D=the horizontal distance=d cos n,

FP=Q=the vertical distance=D tan n

n=the vertical angle,

AGB=$2m$.

It is first required to express d in terms of a, n and m.

From the proportionality existing between the sides of a triangle and the sides of the opposite angles,

$$\frac{AF}{GF}=\frac{\sin m}{\sin\,[90°+(n-m)]}$$

$$\text{or, } AF=GF\sin m\frac{1}{\cos\,(n-m)};$$

$$\text{and}\frac{BF}{GF}=\frac{\sin m}{\sin\,[90°-(n+m)]}$$

$$\text{or, } BF=GF\sin m\frac{1}{(\cos n+m)};$$

$$\therefore AF+BF=GF\sin m\left(\frac{1}{\cos\,n-m)}+\frac{1}{(\cos\,(n+m)}\right)$$

$$AF+BF=a, \text{ and } GF=\frac{CD}{2}\frac{1}{\tan m}=\frac{CD\cos m}{2\sin m}$$

By substituting and reducing to a common denominator,

$$a=\frac{CD}{2}\;\frac{\text{os}m\;[\cos\,(n+m)+\cos\,(n-m)]}{\cos\,(n+m)\cos\,(n-m)}$$

Reducing this according to trigonometrical formulæ,

$$CD=a\frac{\cos^2 n\cos^2 m-\sin^2 n\sin^2 \text{m}}{\cos n\cos^2 m}$$

as d=MF=$c+k$.CD,

$$\therefore\; d=c+k\,a\frac{\cos^2 n\cos^2 m-\sin^2 n\sin^2 m}{\cos n\cos^2 m}$$

The horizontal distance, D=d cos n.

$$\therefore \text{D}=c\cos \text{n}+ka\cos^2 n-k\,a\sin^2 n\tan^2 m.$$

"The third member of this equation may safely be neglected, as it is very small even for long distances and large angles of elevation (for 1500′, n=45° and k=100, it is but 0.07′.) Therefore, the final formula for distances, with a stadia kept vertical, and with wires equidistant from the center wire, is the following:"

$$\text{D}=c\cos n+a\,k\cos^2 n \quad . \quad . \quad (5)$$

The vertical distance Q, is easily obtained from the relation: Q=D tan n.

$$\therefore \text{Q}=c\sin n+a\,k\cos n\sin n$$

$$\text{or Q}=c\sin n+a\,k\frac{\sin 2n}{2} \quad . \quad (6)^*$$

With the aid of formulæ (5) and (6) the horizontal and vertical distances can be immediately calculated when the reading from a *vertical* rod, and the angle of elevation of any sight are given; and it is from these formulæ that I have calculated my stadia reduction tables. The values of $ak\cos^2 n$ and $ak\frac{\sin 2n}{2}$ were separately calculated for each two minutes up to 30 degrees of elevation; but, as the value of $c\sin n$ and $c\cos n$ have quite an inappreciable variation for 1 degree, it was thought sufficient to determine these values only for each degree. As c varies with different instruments these last two expressions were calculated for three different values of c, thus furnishing a ratio from which values of $c\sin n$ and $c\cos n$ can be easily determined for an instrument having any constant (c).

Similar tables have been computed by *J. A. Ockerson* and *Jared Teeple*, of the United States Lake Survey. Their use is, however, limited, from the fact that the meter is the unit of horizontal measurement while the elevations are in feet. The bulk of the tables furnish differences of level for stadia readings up to 400 meters, but only up to 10° of elevation. Supplementary tables give the elevations up to 30° for a distance of one meter. For obtaining horizontal distances reference has to be made to *another* table, which is somewhat an objectionable feature, and a multiplication *and* a subtraction has to be made in order to obtain the result. Last, but not least, these tables are, apparently, only accurate when used with an instrument whose constant is 0.43 meters.

* The above demonstration is substantially that given by Mr. George J. Specht, in an article on Topographical Surveying in *Van Nostrand's Engineering Magazine* for February, 1880, though enlarged and corrected.

As stated in the preceding discussion (p. 314), the generally accepted formula expressing the relation between the distance in a horizontal sight, the reading on the rod, the distance of the stadia wires apart, and the focal length of the objective is

$$d=\frac{f}{\mathrm{I}}a+f \quad . \quad . \quad . \quad . \quad (3)$$

where d, a, I and f represent these factors respectively.

This formula is derived from the conjunction of the two equations:

$$d=\frac{p}{\mathrm{I}}a; \quad . \quad . \quad . \quad . \quad (1)$$

$$\text{and } \frac{1}{p}+\frac{1}{p'}=\frac{1}{f}; \quad . \quad . \quad . \quad (2)$$

p and p' in (2) being considered as equal to p and d in (1). p and d in (1), it will be remembered, are the distances from the *center* of the objective to the image and object respectively. But the general formula for lenses, (2), is derived on the supposition that p and p' are measured from the *exterior faces* of the lens, and therefore p and d in (1) are each greater, by half the thickness of the lens, than p and p' in (2). Further, this formula is derived on the supposition that the object glass of the telescope is a simple, biconvex lens, whereas, in fact, it is a compound lens composed of a plano concave and a biconvex lens. Now, though these points may seem insignificant in themselves, they may greatly influence the final result, as a difference of only 1 in the denominator of such a fraction as $\frac{1{,}000{,}000}{2}$ may alter the result by as much as 500,000. Considerable thought and time has, therefore, been given to the consideration of the effect of these corrections, and, as a result, it was found that the formula (3) does not express the true relation even within practical limits; and that if it were attempted to calculate the distance, d, by this formula, when the factors f, p and a were given, a result would be obtained which would differ considerably from the real distance. The inaccuracy lies in the expression $\frac{f}{\mathrm{I}}$. The one to be substituted for it is, however, like it, a constant for each instrument; and, as we determine the value of this constant by actual trial and not from a knowledge of the values of f and I, the correction to be made will not affect the practice.

Considering first the case of a telescope with a simple, biconvex lens, the optical center being, here, in the center of the lens, d and p, in equation (1), as before stated, are measured from the center of the lens, while, in equation (2), p and p' are measured from the exterior faces. If the thickness of the lens be taken as $2x$, then

p in equation (1)$=p$ in equation (2), minus x; and

p' in equation (1)$=$d in equation (2), minus x.

Therefore, while (1) remains

$$d=\frac{p}{\mathrm{I}}a, \text{ or } p=\frac{\mathrm{I}}{a}d \quad . \quad (1a)$$

by substitution, (2), becomes,

$$\frac{1}{p-x}+\frac{1}{d-x}=\frac{1}{f} \quad . \quad . \quad (2a)$$

Substituting $d\frac{\mathrm{I}}{a}$ for p in (2a)

$$\frac{1}{d\frac{\mathrm{I}}{a}-x}\times\frac{1}{d-x}=\frac{1}{f}$$

$$\therefore d-x+d\frac{\mathrm{I}}{a}-x=\frac{1}{f}\left(d-x\right)\left(d\frac{\mathrm{I}}{a}-x.\right)$$

$$=\frac{1}{f}d^2\frac{\mathrm{I}}{a}-\frac{1}{f}d\frac{\mathrm{I}}{a}x-\frac{1}{f}dx+\frac{1}{f}x^2$$

whence, $-2x-\frac{1}{f}x^2=\frac{1}{f}d^2\frac{\mathrm{I}}{a}$

$$-d\frac{1}{f}x\left(\frac{\mathrm{I}}{a}+1\right)-d\left(\frac{\mathrm{I}}{a}+1\right)$$

or $$=\frac{1}{f}d^2\frac{\mathrm{I}}{a}-d\left\{\left(\frac{\mathrm{I}}{a}+1\right)\left(\frac{1}{f}x+1\right)\right\}.$$

Multiplying both sides by $\frac{\mathrm{I}}{a}\frac{1}{f}$,

$$-\frac{\mathrm{I}}{a}\frac{1}{f}\left(2x+\frac{1}{f}x^2\right)=\frac{1}{f^2}d^2\frac{\mathrm{I}^2}{a^2}$$

$$-\frac{\mathrm{I}}{a}\frac{1}{f}d\left\{\left(\frac{\mathrm{I}}{a}+1\right)\left(\frac{1}{f}x+1\right)\right\}$$

Adding to both sides $\frac{\left\{\left(\frac{\mathrm{I}}{a}+1\right)\left(\frac{1}{f}x+1\right)\right\}}{2}$ squared,

$$\frac{\left\{\left(\frac{\mathrm{I}}{a}+1\right)\left(\frac{1}{f}x+1\right)\right\}^2}{4}-\frac{\mathrm{I}}{a}\frac{1}{f}\left(2x+\frac{1}{f}x^2\right)=\left(d\frac{1}{f}\frac{\mathrm{I}}{a}\right)^2-d\frac{1\mathrm{I}}{fa}$$

$$\left\{\left(\frac{\mathrm{I}}{a}+1\right)\left(\frac{1}{f}x+1\right)\right\}\times\frac{\left\{\left(\frac{\mathrm{I}}{a}+1\right)\left(\frac{1}{f}x+1\right)\right\}^2}{4}$$

Extracting the square root of both terms,

$$\sqrt{\frac{\left\{\left(\frac{\mathrm{I}}{a}+1\right)\left(\frac{1}{f}x+1\right)\right\}^2}{4}}-\frac{1}{f}\frac{\mathrm{I}}{a}\left(2x+\frac{1}{f}x^2\right)=d\frac{1}{f}\frac{\mathrm{I}}{a}-\frac{\left(\frac{\mathrm{I}}{a}+1\right)\left(\frac{1}{f}x+1\right)}{2}$$

Therefore,

$$\left\{\sqrt{\frac{\left\{\left(\frac{\mathrm{I}}{a}+1\right)\left(\frac{1}{f}x+1\right)\right\}^2}{4}}-\frac{1}{f}\frac{\mathrm{I}}{a}\left(2x+\frac{1}{f}x^2\right)+\frac{\left(\frac{\mathrm{I}}{a}+1\right)\left(\frac{1}{f}x+1\right)}{2}\right\}\frac{af}{\mathrm{I}}=k$$

or, $$d=\frac{(\mathrm{I}+a)\,(x+f)}{2\mathrm{I}}+\sqrt{\frac{[(\mathrm{I}+a)(x+f)]^2}{4\mathrm{I}^2}-\frac{a}{\mathrm{I}}(x^2+2xf)} \quad (3a)$$

This is the *exact* formula corresponding to (3), for biconvex lenses. This can, however, be considerably reduced without materially affecting its value. With a telescope of the dimensions of that of an ordinary engineer's transit, the term $\frac{a}{\mathrm{I}}(x^2+2xf)$ diminishes the result by about $\frac{1}{3}$ of an inch and, therefore, may be neglected. Formula (3*a*), then becomes:

$$d=2\frac{(\mathrm{I}+a)\,(x+f)}{2\mathrm{I}}=\frac{\mathrm{I}x+\mathrm{I}f+ax+af}{\mathrm{I}}=a\frac{x+f}{\mathrm{I}}+f+x$$

The addition of x (half the thickness of the object glass) would be inappreciable in the length of any ordinary sight, and may be omitted. The final expression becomes, then,

$$d=\frac{x+f}{\mathrm{I}}a+f \quad . \quad (3b)$$

This formula, it will be observed, differs from (3) in that the reading on the rod (a), is multiplied by $x+f$ instead of f. The numerical difference between the results is seen in the following examples:

Consider first the case with a one-foot reading on the rod, and let $x=.18''$, $f=9.00''$, and $\mathrm{I}=.08''$.*

Formula (3) becomes, then:

$$d=\frac{9.00''}{.08''}12.00''+9.00''=1359''=113.25';$$

Formula (3b) becomes:

$$d=\frac{.18''+9.00''}{.08''}12.00''+9.00''=1386=115.50'$$

Difference = 2.25'

When the reading on the rod is 5 feet (or 60'') then, (3) becomes:

$$d=\frac{9.00''}{.08''}60.00''+9.00=563.25';$$

and (3b) becomes:

$$d=\frac{.18''+9.00''}{.08''}60.00''+9.00=574.50'$$

Difference = 11.25'†

The above demonstration shows, then, that, with a simple biconvex object glass, the usually accepted formula expressing the relation between the distance, the reading on the rod, the distance of the stadia wires apart, and the focal length of the objective, is not accurate even within the limits of accuracy of such measurements. With the usual combination of lenses in objectives this error would still remain. The derivation of a formula similar to (3*b*), for such lenses, would, however, be extremely difficult, and would only hold for the special lens in question. For, with such a combination of lenses, the optical center would no longer remain in the center of the lens, but would vary its position according to the relative thicknesses of the two glasses, their radii of curvature and their

* These are very closely the dimensions in Heller & Brightly's large Surveyor's Transit (5-inch needle), as kindly furnished me by Mr. Heller.

† As the difference is evidently proportional to the length of sight, with a 1000' sight it would amount to 22.5', etc.

indices of refraction; and, after its position had been determined by abstruse calculation and refined experiment, its distance from the two exterior faces of the compound lens would be expressed by *two different* values (x and x') instead of two equal values (x); and this would very much complicate further calculation.

It was seen that, in the newly deduced formula, for biconvex objectives, like that heretofore accepted, the factor by which the reading on the rod is multiplied is a constant for each instrument, and that the practical method of adjusting the instrument remains the same. The question now arises, does this remain the case with a compound objective?

In view of the difficulty of demonstrating this mathematically it was decided to make a practical test of this point with a carefully adjusted instrument. A distance of 500 feet was first measured off on a level stretch of ground, and each 50 foot point accurately located. From one end of this line three successive series of stadia readings* were then taken from the first 50 foot and each succeeding 100 foot mark. The following table contains the results:

Distances.	Spaces Intercepted on the Rod.			
	1st Series.	2d Series.	3d Series.	Mean.
Feet.	Feet.	Feet.	Feet.	Feet.
50.00	.4850	.4860	.4855	.4855
100.00	.9850	.9870	.9830	.9850
200.00	1.9850	1 9860	1.9840	1.9850
300.00	2.9890	2.9875	2.9870	2.9878
400.00	3.9830	3.9800	3.9890	3.9840
500 00	4.9850	4.9850	4.9900	4.9867

Multiplying the mean of these readings by 100, and subtracting the result from the corresponding distance, we obtain the following table:

Distances.	Mean of Stadia Readings times 100.	Differences.	Variations from Mean.
Feet.	Feet.	Feet.	Feet.
50.00	48.55	1.45	+.02
100.00	98.50	1.50	+.07
200.00	198.50	1.50	+.07
300.00	298.78	1.22	−.21
400.00	398.40	1.60	+.17
500.00	498.67	1.33	−.10

Sum of Differences = 8.60;
Mean of Differences = 1.43.

The variations between the numbers of the column of differences are slight, the maximum from a mean value of 1.43 feet being only .21 feet. A study of the tables will show that these variations have no apparent relation to the length of the sight; in the maximum case, the variation corresponds to a reading on the rod of only .0021 feet (an amount much within the limits of accuracy of any ordinary sight). We are, therefore, perfectly justified in concluding that these variations are acci-

* The readings were taken from two targets, set so that the sight should be horizontal and thus also preventing any personal error or prejudice from affecting the reading.

dental, and that the "difference" is, for all practical purposes, a *constant* value.

We thus see that with a telescope having a compound, plano-convex objective, whatever the formula may be expressing the relation between d, f, x, etc., the horizontal distance is equal to a *constant* times the reading on the rod plus a *constant*, and may, as in the other cases, be expressed by the equation,

$$d = ak + c^*$$

The many advantages of stadia measurements in surveying need not be dwelt upon here, both because attention has been repeatedly called to them, and because they are self-evident to every engineer. Neither will it be within the compass of this article to describe the various forms of rods and instruments, or the conventionalities of stadia work.

A few precautions, necessary for accurate work, should, however, be emphasized. First, as regards the special adjustments: care should be taken that in setting the stadia wires† allowance be made for the instrument constant, and that the wires are so set that the reading, at any distance, is less than the true distance by the amount of this constant.‡

For accurate stadia work it is better to take the reading for both distances and elevations only at alternate stations and then to take them from both back and fore sights, in such a manner that the vertical angle is always read from the same position on each rod, which should be the average height of the telescope at the different stations.

Cases will, of course, occur where this method will be impracticable, and then the mode of procedure must be left to the judgment of the surveyor. If it be desired to have the absolute elevation of the ground under the instrument, the height of the telescope at each station will have to be measured by the rod, and the difference between this measurement and the average height used in sighting to the rod either added or subtracted as the case may be. This difference will ordinarily be so small, that in a great deal of stadia work no reduction will be necessary. In sighting to the rod for the angle of depression or elevation, the center horizontal wire must always be used. By this means an exactly continuous line is measured.

For theoretical exactness it is necessary that the stadia wires should be equidistant from the horizontal center wire, for, if this be not the case, the distance read is for an angle of elevation differing from the true one by an amount proportional to the displacement of the wires.

With reasonable care a high degree of accuracy can be attained in stadia measurements. The common errors of stadia reading are unlike the common errors of chaining, the gross ones (such as making a difference of a whole hundred feet) being, in general, the only important ones, and these are readily checked by double readings. To facilitate the subtraction of the reading of one cross hair from that of another, one should be put upon an even foot mark, and in the check reading the other one.

A general measure of the efficiency of stadia measurements is furnished in the professional papers of the Corps of Engineers, U. S. A., for 1882, on the Primary Triangulation of the Lake Survey, where it is stated that. in computing coördinates of stadia work for 1875, the average amount of discrepancy in 141 lines, varying between 965 and 6,648 meters (mean 2,450 meters) when compared with lines determined by triangulation or chaining, was found to be 1 in 649. The maximum limit of error is put at 1 in 300.

Mr. Benjamin Smith Lyman, who has made extensive use of stadia work both in this country and Japan, considers it decidedly more accurate than ordinary good chaining, if the gross errors be carefully avoided.

The results of stadia survey which have come to my notice fully support this view. During the past summer I had occasion to run a continuous stadia line

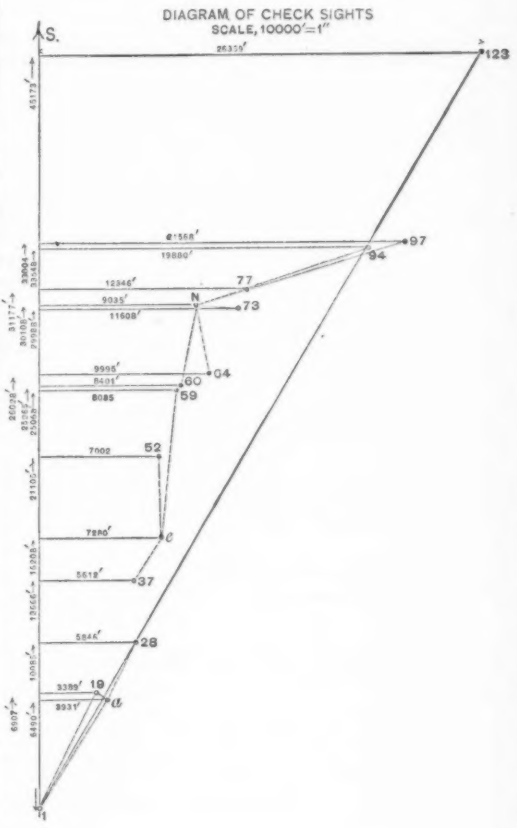
* This may seem a statement of what was already a well-known fact. But, heretofore, it has been assumed to be a direct deduction from optical principles, and as, according to the preceding article, this is not so clearly evident, it seemed necessary to redetermine the point.

† This applies to an instrument with movable stadia wires, and not to one with etched lines on glass. In the latter case the graduation of the rod is the adjustable portion. It has been claimed as an advantage for etched lines on glass, that they are not affected by variations of temperature while the distance between stadia wires is. A series of tests which I made with one of Heller & Brightly's transits, to determine this point, showed no appreciable alteration in the space between the wires, as measured on a rod 500 feet distant, with a range of temperature between that produced in the instrument by the sun of a hot summer's day, and that produced by enveloping the telescope in a bag of ice.

‡ This is assuming the measurements to be made by the ordinary method, and not by the approximate one of the U. S. Engineers.

between two points some twelve miles apart. It was necessary that the position of these points with reference to each other should be determined as closely as possible with the means at hand. In consequence, the work was checked by taking duplicate vernier and stadia readings, and by taking a series of check sights to prominent objects. The latitudes and departures of this survey were afterwards calculated out, and the check angles computed and compared with those observed. The results are shown in the accompanying diagram and table. From the results of the tests tabulated on p.323, Mr. Lyman has kindly furnished me with the following deductions, as an indication of the exactness of stadia measurements.*

Taking the mean, 1.43, as exactly correct, we see, then, that the total error of the eighteen sights was only .06 feet, or $\frac{1}{77600}$ of the whole distance measured, 4,650 feet, a precision (as it happens) seven times greater than I suggested in my paper for a telescope magnifying ten times. But the mean of the errors .000817 (or $\frac{1}{1224}$), which, so far as the insufficient number of eighteen sights can show, would be the mean of the errors of an infinite number of trials, would correspond to a probable error for any one of the number of trials (that is, in gene-



* I wish to take this opportunity to acknowledge my indebtedness to Mr. Benjamin Smith Lyman, for the kindly interest he has taken in the above discussion, for his valuable suggestions, and for his assistance in referring me to various sources for information.

TABLE OF CHECK ANGLES.

Sights.	Course as read.	Course as Deduced.	Difference.	Minimum Proportional Linear Displacement.
19—1	N. 26° 9′ E.	N. 26° 8′ E.	0° 1′	1.3′ E.
28—*a*	N. 28° 8′ E.	N. 28° 3′ E.	0° 5′	5.6′ E.
59—*e*	N. 5° 9′ E.	N. 5° 12′ E.	0° 3′	7 6′ W.
73—N	S. 87° 14′ E.	S. 87° 19′ E.	0° 5′	3.6′ S.
77—N	N. 72° 8′ E.	N. 72° 7′ E.	0° 1′	1.0′ S.
94—N	N. 72° 26′ E.	N. 72° 24′ E.	0° 2′	6.0′ S.
97—N	N. 73° 35′ E.	N. 73° 34′ E.	0° 1′	3.6′ S.

" Distances.	Variations from Mean.	Error (or Variation from Mean) in Parts of the Distance Measured.	Mean Magnitude.
50 feet.	+.07 −.03 +.02	+.0014 −.0006 +.0004	.0008
100 "	+.07 −.13 +.27	+.0007 −.0013 +.0027	.0016
200 "	+.07 −.03 +.17	+.00035 −.0015 +.00085	.00045
300 "	−.33 −.18 −.13	−.0011 −.0006 −.00043	.00071
400 "	+.27 +.57 −.33	+.000675 +.0014 −.00082	.000965
500 "	+.07 +.07 −.43	+.00014 +.00014 −.00086	.00038
	+.22 +.27 −.43=6		6).004905
			.000817

ral) of the same kind, of .00069, or $\frac{1}{1450}$. This is within half the exactness I claimed as possible for the stadia in my paper. The difference may be due to several causes that I neglected to consider, such as a slight leaning of the rod forward or back, imperfect graduation of the rod, imperfect cleanliness or transparency of the glasses or of the air, imperfection in the shape of the lenses, or in their adjustments to one another, waviness from the varying refraction of the air with the heat from the sun and the ground, inaccurate focussing, inexact placing of the center hair upon the center of the target or graduation. This last difficulty might be avoided by taking one edge of the upper or lower cross hairs, and by special painting of the target for the center hair.

* * * But at any rate the superior exactness of stadia measurement over chaining is shown, so far as eighteen trials could do it."

Tables of Horizontal Distances and Differences of Level for Stadia Measurements.

The formulæ used in the computation of the following tables, were those given by Mr. Geo. J. Specht in an article on Topographical Surveying, published in Van Nostrand's Engineering Magazine for February, 1880. These formulæ furnish expressions for horizontal distances and differences of level for stadia measurements with the conditions that the stadia rod *be held vertical*, and the stadia wires be equidistant from the centre wire. They are as follows:

$$D = c \cos n + ak \cos {}^2 n.$$

$$Q = D \tan n = c \sin n + \frac{ak \sin 2n}{2}.$$

D=Horizontal distance.

Q=Difference of level.

c=the distance from the center of the instrument to the center of the object glass, plus the focal length of the object glass.

k=the focal length of the object glass divided by the distance of the stadia wires apart.

a=the reading on the stadia rod.

n=the vertical angle.

ak is the reading on the rod multiplied by k, which is a constant for each instrument (generally 100.) In the tables the vertical columns consist of two series of numbers for each degree, which series represent respectively the different values of $ak \cos {}^2 n$ and $\frac{ak \sin 2n}{2}$ for every two minutes, when $ak=100$. To obtain the horizontal distance or the difference of level in any case, the corresponding value of $c \cos n$ or $c \sin n$ must further be added, and the mean of each of these expressions, for each degree, with 3 of the most common values of c, is given under each column.

As an example, let it be required to find the horizontal distance and the difference of level when, $n=+6°\ 18'$, $ak=570$, and the instrument constant, $c=.75$. In the column headed 6°, opposite 18′ in the series for " Hor. Dist.," we find 98.80 as the expression for $ak \cos {}^2 n$ when $ak=100$, therefore, when $ak=570$.

$ak \cos {}^2 n = 98.80 \times 5.70 = 563.16$.

To this must be added $c \cos n$, which in this case is found in the subjoined column to be .75.

M.	0°		1°		2°		3°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0′....	100.00	.00	99.97	1.74	99.88	3.49	99.73	5.23
2.....	"	.06	"	1.80	99.87	3.55	99 72	5.28
4.....	"	.12	"	1.86	"	3.60	99.71	5.34
6.....	"	.17	99.96	1.92	"	3.66	"	5.40
8.....	"	.23	"	1.98	99.86	3.72	99.70	5.46
10.....	"	.29	"	2.04	"	3.78	99.69	5.52
12.....	"	.35	"	2.09	99.85	3.84	"	5.57
14.....	"	.41	99.95	2.15	"	3.90	99.68	5.63
16.....	"	.47	"	2.21	99.84	3.95	"	5.69
18.....	"	.52	"	2.22	"	4.01	99.67	5.75
20.....	"	.58	"	2.33	99.83	4.07	99.66	5.80
22.....	"	.64	99 94	2.38	"	4.13	"	5.86
24.....	"	.70	"	2.44	99.82	4.18	99.65	5.92
26.....	99.99	.76	"	2.50	"	4.24	99.64	5.98
28.....	"	.81	99.93	2.56	99.81	4.30	99.63	6.04
30.....	"	.87	"	2.62	"	4.36	"	6.09
32.....	"	.93	"	2.67	99.80	4.42	99.62	6.15
34.....	"	.99	"	2.73	"	4.48	"	6.21
36.....	"	1.05	99.92	2.79	99.79	4.53	99.61	6.27
38.....	"	1.11	"	2.85	"	4.59	99.60	6.33
40.....	"	1.16	"	2.91	99.78	4.65	99.59	6.38
42.....	"	1.22	99.91	2.97	"	4.71	"	6.44
44.....	99.98	1.28	"	3.02	99.77	4.76	99.58	6.50
46.....	"	1.34	99.90	3.08	"	4.82	99.57	6.56
48.....	"	1.40	"	3.14	99.76	4.88	99.56	6.61
50.....	"	1.45	"	3.20	"	4.94	"	6.67
52.....	"	1.51	99.89	3.26	99.75	4.99	99.55	6.73
54.....	"	1.57	"	3.31	99.74	5.05	99.54	6.78
56.....	99.87	1.63	"	3.37	"	5.11	99.53	6.84
58.....	"	1.69	99.88	3.43	99.73	5.17	99.52	6.90
60.....	"	1.74	"	3.49	"	5.23	99.51	6.96
c= .75	.75	.01	.75	.02	.75	.03	.75	.05
c=1.00	1.00	.01	1.00	.03	1.00	.04	1.00	.06
c=1.25	1.25	.02	1.25	.03	1.25	.05	1.25	.08

M.	8°		9°		10°		11°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0′....	98.06	13.78	97.55	15.45	96.98	17.10	96.36	18.73
2.....	98.05	13.84	97.53	15.51	96.96	17.16	96.34	18.78
4.....	98.03	13.89	97.52	15.56	96.94	17.21	96.32	18.84
6.....	98.01	13.95	97.50	15.62	96.92	17.26	96.29	18.89
8.....	98.00	14.01	97.48	15.67	96.90	17.32	96.27	18.95
10.....	97.98	14.06	97.46	15.73	96.88	17.37	96.25	19.00
12.....	97.97	14.12	97.44	15.78	96.86	17.43	96.23	19.05
14.....	97.95	14.17	97.43	15.84	96.84	17.48	96.21	19.11
16.....	97.93	14.23	97.41	15 89	96.82	17.54	96.18	19.16
18.....	97.92	14.28	97.39	15.95	96.80	17.59	96.16	19.21
20.....	97.90	14.34	97 37	16.00	96.78	17.65	96.14	19.27
22.....	97.88	14.40	97.35	16.06	96.76	17.70	96.12	19.32
24.....	97.87	14.45	97.33	16.11	96.74	17.76	96.09	19.38
26.....	97.85	14.51	97.31	16.17	96.72	17.81	96.07	19.43
28.....	97.83	14.56	97.29	16.22	96.70	17.86	96.05	19.48
30.....	97.82	14.62	97.28	16.28	96.68	17.92	96.03	19.54
32.....	97.80	14.67	97.26	16.33	96.66	17.97	96.00	19.59
34.....	97.78	14.73	97.24	16.39	96.64	18.03	95.98	19.64
36.....	97.76	14.79	97.22	16.44	96.62	18.08	95.96	19.70
38.....	97.75	14.84	97.20	16.50	96.60	18.14	95.93	19.75
40.....	97.73	14.90	97.18	16.55	96.57	18.19	95.91	19.80
42.....	97.71	14.95	97.16	16.61	96.55	18.24	95.89	19.86
44.....	97.69	15.01	97.14	16.66	96.53	18.30	95.86	19.91
46.....	97.68	15.06	97.12	16.72	96.51	18.35	95.84	19.96
48.....	97.66	15.12	97.10	16.77	96.49	18.41	95.82	20.02
50.....	97.64	15.17	97.08	16.83	96.47	18.46	95.79	20.07
52.....	97.62	15.23	97.06	16.88	96.45	18.51	95.77	20.12
54.....	97.61	15.28	97.04	16.94	96.42	18.57	95.75	20.18
56.....	97.59	15.34	97.02	16.99	96.40	18.62	95.72	20.23
58.....	97.57	15.40	97.00	17.05	96.38	18.68	95.70	20.28
60.....	97.55	15.45	96.98	17.10	96.36	18.73	95.68	20.34
c= .75	.74	.11	.74	.12	.74	.14	.73	.15
c=1.00	.99	.15	.99	.16	.98	.18	.98	.20
c=1.25	1.23	.18	1.23	.21	1.23	.23	1.22	.25

M.	4°		5°		6°		7°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0′....	95.51	6.96	99.24	8.68	98.91	10.40	98.51	12.10
2.....	"	7.02	99.23	8.74	98.90	10.45	98.50	12.15
4.....	99.50	7.07	99.22	8.80	98.88	10.51	98.48	12.21
6.....	99.49	7.13	99.21	8.85	98.87	10.57	98.47	12.26
8.....	99.48	7.19	99.20	8.91	98.86	10.62	98.46	12.32
10.....	99.47	7.25	99.19	8.97	98.85	10.68	98.44	12.38
12.....	99.46	7.30	99.18	9.03	98.83	10.74	98.43	12.43
14.....	"	7.36	99.17	9.08	98.82	10.79	98.41	12.49
16.....	99.45	7.42	99.16	9.14	98.87	10.85	98.40	12.55
18.....	99.44	7.48	99.15	9.20	98.80	10.91	98.39	12.60
20.....	99.43	7.53	99.14	9.25	98.78	10.96	98.37	12.66
22.....	99.42	7.59	99.13	9.31	98.77	11.02	98.36	12.72
24.....	99.41	7.65	99.11	9.37	98.76	11.08	98.34	12.77
26.....	99.40	7.71	99.10	9.43	98.74	11.13	98.33	12.83
28.....	99.39	7.76	99.09	9.48	98.73	11.19	98.31	12.88
30.....	99.38	7.82	99.08	9.54	98.72	11.25	98.29	12.94
32.....	99.38	7.88	99.07	9.60	98.71	11.30	98.28	13.00
34.....	99.37	7.94	99.06	9.65	98.69	11.36	98.27	13.05
36.....	99.36	7.99	99.05	9.71	98.68	11.42	98.25	13.11
38.....	99.35	8.05	99.04	9.77	98.67	11.47	98.24	13.17
40.....	99.34	8.11	99.03	9.83	98.65	11.53	98.22	13.22
42.....	99.33	8.17	99.01	9.88	98.64	11.59	98.20	13.28
44.....	99.32	8.22	99.00	9.94	98.63	11.64	98.19	13.33
46.....	99.31	8.28	98.99	10.00	98.61	11.70	98.17	13.39
48.....	99.30	8.34	98.98	10.05	98.60	11.76	98.16	13.45
50.....	99.29	8.40	98.97	10.11	98.58	11.81	98.14	13.50
52.....	99.28	8.45	98.96	10.17	98.57	11.87	98.13	13.56
54.....	99.27	8.51	98.94	10.22	98.56	11.93	98.11	13.61
56.....	99.26	8.57	98.93	10.28	98.54	11.98	98.10	13.67
58.....	99.25	8.63	98.92	10.34	98.53	12.04	98.08	13.73
60.....	99.24	8.68	98.91	10.40	98.51	12.10	98.06	13.78
c= .75	.75	.06	.75	.07	.75	.08	.74	.10
c=1.00	1.00	.08	.99	.09	.99	.11	.99	.13
c=1.25	1.25	.10	1.24	.11	1.24	.14	1.24	.16

M.	12°		13°		14°		15°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0′....	95.68	20.34	94.94	21.92	94.15	23.47	93.30	25.00
2.....	95.65	20.39	94.91	21.97	94.12	23.52	93.27	25.05
4.....	95.63	20.44	94.89	22.02	94.09	23.58	93.24	25.10
6.....	95.61	20.50	94 86	22.08	94.07	23.63	93.21	25.15
8.....	95.58	20.55	94.84	22.13	94.04	23.68	93.18	25.20
10.....	95.56	20.60	94.81	22.18	94.01	23.73	93.16	25.25
12.....	95 53	20.66	94.79	22.23	93.98	23.78	93.13	25.30
14.....	95.51	20.71	94.76	22.28	93.95	23.83	93.10	25.35
16.....	95.49	20.76	94.73	22.34	93.93	23.88	93.07	25.40
18.....	95.46	20.81	94.71	22.39	93.90	23.93	93.04	25.45
20.....	95.44	20.87	94.68	22.44	93.87	23.99	93.01	25.50
22.....	95.41	20.92	94.66	22.49	93.84	24.04	92.98	25.55
24.....	95.39	20.97	94.63	22.54	93.81	24.09	92.95	25.60
26.....	95.36	21.03	94.60	22.60	93.79	24.14	92 92	25.65
28.....	95.34	21.08	94.58	22.65	93.76	24.19	92.89	25.70
30.....	95.32	21.13	94.55	22.70	93.73	24.24	92.86	25.75
32.....	95.29	21.18	94.52	22.75	93.70	24.29	92.83	25.80
34.....	95.27	21.24	94.50	22.80	93.67	24.34	92.80	25.85
36.....	95.24	21.29	94.47	22.85	93.65	24.39	92.77	25.90
38.....	95.22	21.34	94.44	22.91	93.62	24.44	92.74	25.95
40.....	95.19	21.39	94.42	22.96	93.59	24.49	92.71	26.00
42.....	95.17	21.45	94.39	23.01	93.56	24.55	92.68	26.05
44.....	95.14	21.50	94.36	23.06	93.53	24.60	92.65	26.10
46.....	95.12	21.55	95.34	23.11	93.50	24.65	92.62	26.15
48.....	95.09	21.60	94.31	23.16	93.47	24.70	92.59	26.20
50.....	95.07	21.66	94.28	23.22	93.45	24.75	92.56	26.25
52.....	95.04	21.71	94.26	23.27	93.42	24.80	92.53	26.30
54.....	95.02	21.76	94.23	23.32	93.39	24.85	92.49	26.35
56.....	94.99	21.81	94.20	23.37	93.36	24.90	92.46	26.40
58.....	94.97	21.87	94.17	23.42	93.33	24.95	92.43	26.45
60.....	94.94	21.92	94.15	23.47	93.30	25.00	92.40	26.50
c= .75	.73	.16	.73	.17	.73	.19	.72	.20
c=1 00	.98	.22	.97	.23	.97	.25	.96	.27
c=1.25	1.22	.27	1.21	.29	1.21	.31	1.20	.34

M.	16°		17°		18°		19°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0′....	92.40	26.50	91.45	27.96	90.45	29.39	89.40	30.78
2.....	92.37	26.55	91.42	28.01	90.42	29.44	89.36	30.83
4.....	92.34	26.59	91.39	28.06	90.38	29.48	89.33	30.87
6.....	92.31	26.64	91.35	28.10	90.35	29.53	89.29	30.92
8.....	92.28	26.69	91.32	28.15	90.31	29.58	89.26	30.97
10.....	92.25	26.74	91.29	28.20	90.28	29.62	89.22	31.01
12.....	92.22	26.79	91.36	28.25	90.24	29.67	89.18	31.06
14.....	92.19	26.84	91.32	28.30	90.21	29.72	89.15	31.10
16.....	92.15	26.89	91.19	28.34	90.18	29.76	89.11	31.15
18.....	92.12	26.94	91.16	28.39	90.14	29.81	89.08	31.19
20.....	92.09	26.99	91.12	28.44	90.11	29.86	89.04	31.24
22.....	92.06	27.04	91.09	28.49	90.07	29.90	89.00	31.28
24.....	92.03	27.09	91.06	28.54	90.04	29.95	88.96	31.33
26.....	92.00	27.23	91.02	28.58	90.00	30.00	88.93	31.38
28.....	91.97	27.18	90.99	28.63	89.97	30.04	88 89	31.42
30.....	91.93	27.23	90.96	28.68	89.93	30.09	88.86	31.47
32.....	91.90	27.28	90.92	28.73	89.90	30.14	88.82	31.51
34.....	91.87	27.33	90.89	28.77	89.86	30.19	88.78	31.56
36.....	91.84	27.38	90 86	28.82	89.83	30.23	88.75	31.60
38.....	91.81	27.43	90.82	28.87	89.79	30.28	88.71	31.65
40.....	91.77	27.48	90.79	28.92	89.76	30.32	88.67	31 69
42.....	91.74	27.52	90.76	28.96	89.72	30.37	88.64	31.74
44.....	91.71	27.57	90.72	29.01	89.69	30.41	88.60	31.78
46.....	91.68	27.62	90.69	29.06	89.65	30.46	88.55	31.83
48.....	91.65	27.67	90.66	29.11	89.61	30.51	88.53	31.87
50.....	91.61	27.72	90.62	29.15	89.58	30.55	88.49	31.92
52.....	91.58	27.77	90.59	29.20	89.54	30.60	88.45	31.96
54.....	91.55	27.81	90.55	29.25	89.51	30.65	88.41	32.01
56.....	91.52	27.86	90.52	29.30	89.47	30.69	88.38	32.05
58.....	91.48	27.96	90.48	29.34	89.44	30.74	88.34	32.09
60.....	91.45	27.96	90.45	29.39	89.40	30.78	88.30	32.14
c= .75	.72	.21	.72	.23	.71	.24	.71	.25
c=1.00	.86	.28	.95	.30	.95	.32	.94	.33
c=1.25	1.20	.35	1.19	.38	1.19	.40	1.18	.42

M.	24°		25°		26°		27°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0′....	83.46	37.16	82.14	38.30	80.78	39.40	79.39	40.45
2.....	83.41	37.20	82.09	38.34	80.74	39.44	79.34	40.49
4.....	83.37	37.23	82.05	38.38	80.69	39.47	79.30	40.52
6.....	83.33	37.27	82.01	38.41	80.65	39.51	79.25	40 55
8.....	83.28	37.31	81.96	38.45	80.60	39.54	79.20	40.59
10.....	83.24	37.35	81.92	38.49	80.55	39.58	79.15	40.62
12.....	83.20	37.39	81.87	38.53	80.51	39.61	79.11	40.66
14.....	83.15	37.43	81.83	38.56	80.46	39.65	79.06	40.69
16.....	83.11	37.47	81.78	38.60	80.41	39.69	79.01	40.72
18.....	83.07	37.51	81.74	38.64	80.37	39.72	78.96	40.76
20.....	83.02	37.54	81.69	38.67	80.32	39.76	78.92	40.79
22.....	82.98	37.58	81.65	38.71	80.28	39.79	78.87	40.82
24.....	82.93	37.62	81.60	38.75	80.23	39.83	78.82	40.86
26.....	82.89	37.66	81.56	38.78	80.18	39.86	78.77	40.89
28.....	82.85	37.70	81.51	38.82	80.14	39.90	78.73	40.92
30.....	82.80	37.74	81.47	38.86	80.09	39.93	78.63	40.96
32.....	82.76	37.77	81.42	38.89	80.04	39.97	78.63	40.99
34.....	82.72	37.81	81.38	38.93	80.00	40.00	78.58	41.02
36.....	82.67	37.85	81.33	38.97	79.95	40.04	78.54	41.06
38.....	82 63	37.89	81.28	39.00	79.90	40.07	78.49	41.09
40.....	82.58	37.93	81.24	39.04	79.86	40.11	78.44	41.12
42.....	82.54	37.96	81.19	39.08	79.81	40.14	78.39	41.16
44.....	82.49	38.00	81.15	39.11	79.76	40.18	78.34	41.19
46.....	82.45	38.04	81.10	39.15	79.72	40.21	78.30	41.22
48.....	82 41	38.08	81.06	39.18	79.67	40.24	78.25	41.26
50.....	82.36	38.11	81.01	39.22	79.62	40.28	78.20	41.29
52.....	82.32	38.15	80.97	39.26	79.58	40.31	78.15	41.32
54.....	82.27	38.19	80.92	39.29	79.53	40.35	78.10	41.35
56.....	82.23	38.23	80.87	39.33	79.48	40.38	78.06	41.39
58.....	82.18	38.26	80.83	39.36	79.44	40.42	78.01	41.42
60.....	82.14	38.30	80.78	39.40	79.39	40.45	77.96	41.45
c= .75	.68	.31	.68	.32	.67	.33	.66	.35
c=1.00	.91	.41	.90	.43	.89	.45	.89	.46
c=1.25	1.14	.52	1.13	.54	1.12	.56	1.11	.58

M.	20°		21°		22°		23°	
	Hor. Dist	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dis.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0′....	88.30	32.14	87.16	33.46	85.97	34.73	84.73	35.97
2.....	88.26	32.18	87.12	33.50	85.93	34.77	84.69	36.01
4.....	88.23	32.23	87.08	33.54	85.89	34.82	84.65	36.05
6.....	88.19	32.27	87.04	33.59	85.85	34.86	84.61	36.09
8.....	88.15	32.32	87.00	33.63	85.80	34.90	84.57	36.13
10.....	88.11	32.36	86.96	33.67	85.76	34.94	84.52	36.17
12.....	88.08	32.41	86.92	33.72	85.72	34.98	84.48	36.21
14.....	88.04	32.45	86.88	33.76	85.68	35.02	84.44	36.25
16.....	88.00	32.49	86.84	33.80	85.64	35.07	84.40	36.29
18.....	87.96	32.54	86.80	33.84	85.60	35.11	84.35	36.33
20.....	87.93	32.58	86.77	33.89	88.56	35.15	84.31	36.37
22.....	87.89	32.63	86.73	33.93	85.52	35.19	84.27	36.41
24.....	87.85	32.67	86.69	33.97	85.48	35.23	84.23	36.45
26.....	87.81	32.72	86.65	34.01	85.44	35 27	84.18	36.49
28.....	87.77	32.76	86.61	34.06	85.40	35.31	84.14	36.53
30.....	87.74	32.80	86.57	34.10	85.36	35.36	84.10	36.57
32.....	87.70	32.85	86.53	34.14	85.31	35.40	84.06	36.61
34.....	87.66	32.89	86.49	34.18	85.27	35.44	84.01	36.65
36.....	87.62	32.93	86.45	34.23	85.23	35.48	83.97	36.69
38.....	87.58	32.98	86.41	34.27	85.19	35.52	83.93	36.73
40.....	87.54	33.02	86.37	34.31	85.15	35.56	83.89	36.77
42.....	87.51	33.07	86.33	34.35	85.11	35.60	83.84	36.80
44.....	87.47	33.11	86.29	34.40	85.07	35.64	83.80	36.84
46.....	87.43	33.15	86.25	34.44	85.02	35.68	83.76	36.88
48.....	87.39	33.20	86.21	34.48	84.98	35.72	83.72	36.92
50.....	87.35	33.24	86.17	34.52	84.94	35.76	83.67	36.96
52.....	87.31	33 28	86.13	34.57	84.90	35.80	83.63	37.00
54.....	87.27	33.33	86.09	34.61	84.86	35.85	83.59	37.04
56.....	87.24	33.37	86.05	34.65	84.82	35.89	83.54	37.08
58.....	87.20	33.41	86.01	34.69	84.77	35.93	83.50	37.12
60.....	87.16	33.46	85.97	34.73	84.73	35.97	83.46	37.16
c= .75	.70	.26	.70	.27	.69	.29	.69	.30
c=1.00	.94	.35	.93	.37	.92	.38	.92	.40
c=1.25	1.17	.44	1.16	.46	1.15	.48	1.15	.50

M.	28°		29°		30°	
	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0′....	77.96	41.45	76.50	42.40	75.00	43.33
2.....	77.91	41.48	76.45	42.43	74.95	43.30
4.....	77.86	41.52	76.40	42.46	74.90	43.36
6.....	77.81	41.55	76.35	42.49	74.85	43.39
8.....	77.77	41.58	76.30	42.53	74.80	43.42
10.....	77.72	41.61	76.25	42.56	74.75	43.45
12.....	77.67	41.65	76.20	42.59	74.70	43.47
14.....	77.62	41.68	76.15	42.62	74.65	43.50
16.....	77.57	41.71	76.10	42.65	74.60	43.53
18.....	77.52	41.74	76.05	43.68	74.55	43.56
20.....	77.48	41.77	76.00	42.71	74.49	43.59
22.....	77.42	41.81	75.95	42.74	74.44	43.62
24.....	77.38	41.84	75.90	42.77	74.39	43.65
26.....	77.33	41.87	75.85	42.80	74.34	43.67
28.....	77.28	41.90	75.80	42.83	74.29	43.70
30.....	77.23	41.93	75.75	42.86	74.24	43.73
32.....	77.18	41.97	75.70	42.89	74.19	43.76
34.....	77.13	42.00	75.65	42.92	74.14	43.79
36.....	77.09	42 03	75.60	42.95	74 09	43.82
38.....	77.04	42.06	75.55	42.98	74.04	43.84
40.....	76.99	42.09	75.50	43.01	73.99	43.87
42.....	76.94	42.12	75.45	43.04	73.93	43.90
44.....	76.89	42.15	75.40	43.07	73.88	43.93
46.....	76.84	42.19	75 35	43.10	73.83	43.95
48.....	76.79	42.22	75.30	43.13	73.78	43.98
50.....	75.74	42.25	75.25	43.16	74.73	44.01
52.....	76.69	42.28	75.20	33.18	73.68	44.04
54.....	76.64	42.31	75.15	42.21	73.63	44.07
56.....	76.59	42.34	75.10	43.24	73.58	44.09
58.....	76.55	42.37	75.05	43.27	73.52	44.12
60.....	76.50	42.40	75.00	43.30	73 47	44.15
c= .75	.66	.36	.65	.37	.65	.38
c=1.00	.88	.48	.87	.49	.86	.51
c=1.25	1.10	.60	1.09	.62	1.08	.64

$563.16+.75=563.91$, which is the required horizontal distance.

In a similar manner,

$10.91\times5.70+.08=62.27$ is the required difference of level. One multiplication and one addition must be made in each case.

It is to be noticed, that, with the smaller angles, cos n may be neglected in the expression c cos n, and c sin n may be entirely neglected, without appreciable error.

For values of c which differ from those given, an approximate correction proportional to the amount of difference may very easily be made in these two expressions.

TESTING MACHINES, THEIR HISTORY, CONSTRUCTION AND USE.

By ARTHUR V. ABBOTT.

Written for VAN NOSTRAND'S ENGINEERING MAGAZINE.

II.

QUALIFICATIONS OF TESTING MACHINES.

A testing machine should possess the following qualifications:

FIRST, ACCURACY.—The accuracy of a testing machine should be commensurate with the work that it is required to perform. A testing machine used for breaking bridge bars would not need that accuracy or sensitiveness which would be necessary in a contrivance designed to test silk thread.

SECOND, THE CAPABILITY OF BEING TESTED.—Even the most perfect mechanical contrivances are liable to derangement, and the testing machine, used for heavy work, constantly being subjected to the most severe shocks, its parts being strained to an amount exceeding that provided for in the original design, is especially liable to get out of order. Obviously, a machine so designed as to be tested with ease and facility is exceedingly desirable.

THIRD, A DESIGN EMBRACING A READY ADAPTABILITY TO VARIOUS SHAPES AND SIZES OF SPECIMENS.—In the miscellaneous practice of making experiments on various kinds of material in various stresses, it becomes exceedingly important to a rapid and economical use of the testing machine that it may be readily changed from tension to compression, from compression to torsion, from torsion to transverse stress, and that it should be so planned as to take in a long or short specimen with equal facility.

FOURTH, A RAPID MEANS OF MANIPULATION.—The method of applying the stress, of adjusting the specimen in the machine, and of arranging the various parts, one with reference to another, should be so designed that even in the largest machines all the manipulation that is necessary to making a test itself can be accomplished by a single skilled operator.

FIFTH, SELF-RECORDING DEVICES.—As far as is possible in mechanical construction, the machine should be so planned as to make its own record. The advantages of this may be readily seen in the fact that it prevents the possibility of mistakes on the part of the operator, who, even with the most perfect machines, has so much to do in watching the behavior of the specimen during the test, in regulating the rapidity and direction of application of the stress, as to render it expedient to make the machine itself record, as far as possible, all the important facts that are developed by the experiment. In the light of the foregoing qualifications a number of machines may be now considered.

The Gill machine may be regarded as an exceedingly compact and in many respects desirable form of testing machine for investigating the qualities of specimens of materials. The machine occupies comparatively little room. It may be readily manipulated by means of a hand wheel and belt for communicating power to the screw. The two cross-heads

of the machine are accurately bored after all parts of the machine are set up. As a consequence of this, the axis of the machine coincides almost exactly with the axis of stress applied by the machine, and if the specimen to be tested be carefully turned or planed from end to end, and if exceeding care be exercised in setting the piece in the jaws so that the center of the piece shall agree with the center of the testing machine, it is probable that the axis of stress will nearly or quite coincide with the axis of the piece. The stress produced on the specimen is estimated by the system of levers placed above it. There is, however, no method of testing the accuracy of the machine, except by calculating the ratios of the levers or by taking the machine apart and testing each lever separately, and when first built there is no doubt of a reasonable amount of accuracy. Still there being no method of testing the co-efficients of friction of the levers in their actual place, and no method of ascertaining how accurately the entire apparatus weighs, there would arise in minds at least some question as to the results. The Gill machine is simply arranged for tension and requires additional appliances occupying some considerable time in attaching and adjusting to enable it to operate in compression, while the other stresses, such as shearing, bulging, punching, torsion and the like require special appliances not furnished with the machine.

The Olsen machine possesses some points of advantage over the Gill. Here the stress is transmitted through the specimen to the small platform mounted on a different lever contained underneath. By removing the columns, and the crossheads with the screws from the machine, weights to any amount may be piled on the platform by placing thereon a support large enough to contain them. By this means it is possible to test the accuracy of the machine. The use of the differential lever may, however, be somewhat criticised as being liable to a much greater variation in accuracy than the ordinary simple lever system. Here the change from tension to compression is comparatively easily made, for all that is necessary is to place the specimen under the cross-head instead of on the top of it.

The change to transverse, shearing and torsion specimens is made with considerable difficulty. In fact the transverse specimens of any great length are with difficulty accommodated.

In the Riehle machine, tension and compression specimens are easily arranged, but like the Gill machine there are no facilities for testing the machine itself, and reliance must be placed on the accuracy and the care of the makers.

The Emery machine exemplifies one of the best possible contrivances for rapidly changing from tension to compression. Here the hydraulic support is so arranged as to weigh equally as well on either side of it. The jack is sustained on the adjusting screws of the machine by two large bronze nuts, so that all that is necessary to do to change from tension to compression is to reverse the direction of the fluid in the jack so as to cause it to pass from the front to the back of the piston. The method of providing for different lengths of specimens is exceedingly rapid. Along the bottom of the machine there passes a driving shaft connecting with a system of gear work for turning the bronze nuts. By simply starting the belt for communicating power to the shaft, these nuts may be turned either backward or forward at pleasure, and the jack in a short time adjusted to any different length of specimen. The machine, however, has no appliances for making tests in other stresses than those of tension and compression. Being a horizontal machine, it is not susceptible of an easy test. In order to ascertain whether the accuracy of the machine is maintained, it is necessary to take the weighing end of the machine apart, turn the hydraulic support from its seat, and build a platform to contain the necessary amount of standard weights. While there is every presumption that the Emery machine, having been once carefully and accurately standarized, will for a long time retain this accuracy, there will arise in the minds of those subject to accurate scientific considerations, that the change in the molecular constitution of the diaphgram and of the suspended metallic strips, may sooner or later introduce some (be it very slight) error in the accuracy of this contrivance, so that without some easy method of frequent standardization, the results of the machine are liable to criticism. The only method of insuring the coincidents of the axis of

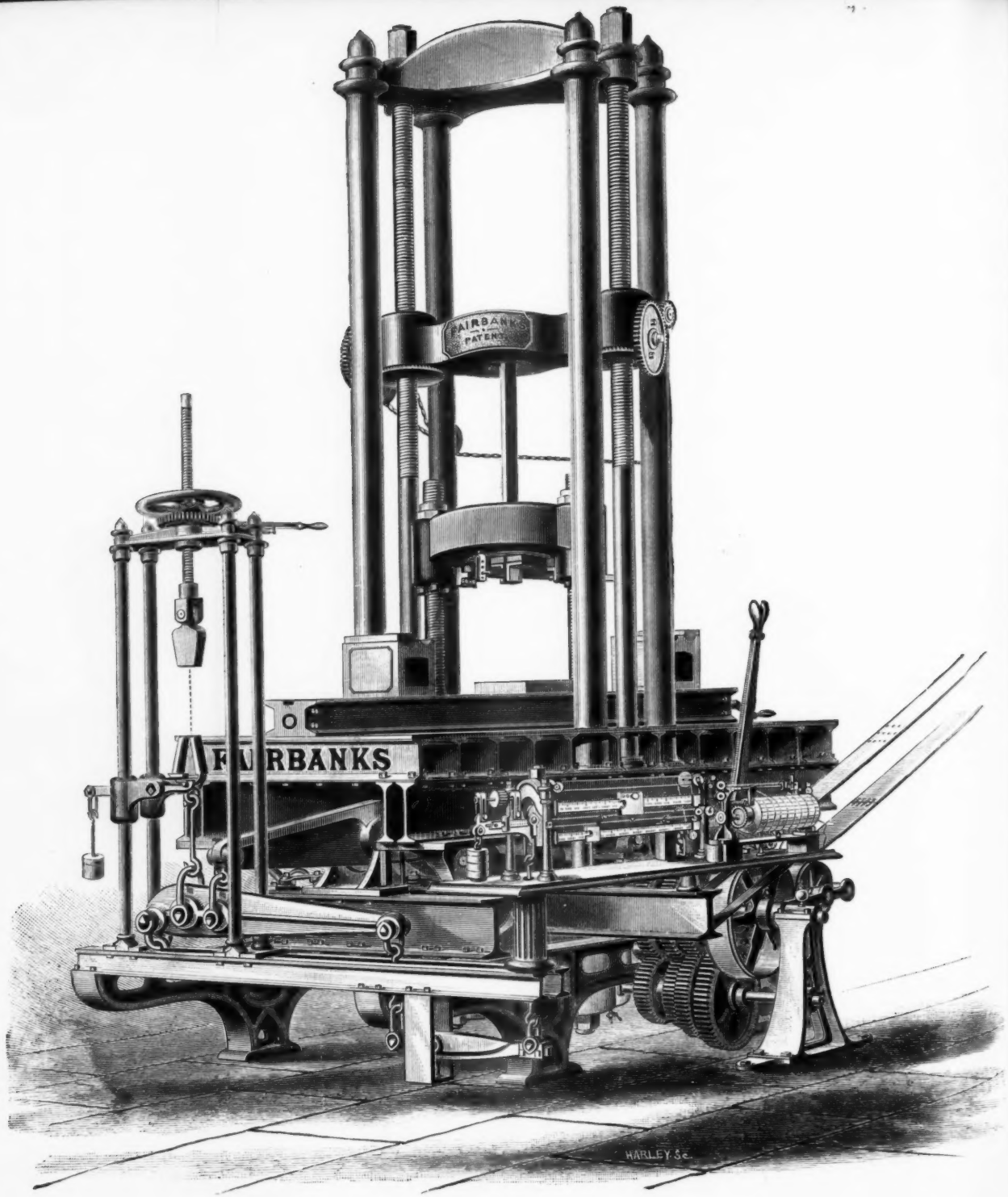


Fig. 8.

stress and the axis of the specimen is by carefully measuring and centering the piece with reference to the axis of the machine, and in one built on so large a scale as that at the Watertown Arsenal, much more time may be consumed in this process of centering than in any other part of the test.

In Fig. 8 a large machine on the Fairbanks' system may be seen, which has recently been constructed with a view to improve on previous machines, and to fulfill the foregoing conditions as far as possible. The lower part of the machine consists of a frame-work of wrought-iron I-beams, standing on two heavy cast iron legs. This frame-work of I-beams supports in the center two screws that may be rotated by the belt or a gearing shown at the left hand. These screws rise in the center of the testing machine and carry the lower cross-head to which one end of the specimen to be examined is attached. Just outside these screws stand a second pair of screws, carrying a top cross-head for the reception of the other end of the test piece. These screws are suspended from a large casting supported on four columns that stand on a second frame-work of I-beams that form a platform of the machine. This large platform some 4 ft. by 10 ft. stands on four levers in a manner similar to that described in the previous testing machine of this system. These levers transfer their stress to two central levers, whence it runs to a couple of multiplying levers, shown in the front of the machine, and then directly to the scale beam. Just in front of the testing machine, standing over the first one of the multiplying levers, may be seen a small frame-work composed of iron columns, carrying on its top a hand wheel and lever. This is an auxiliary testing machine adapted to making tests on small specimens. The large machine has a capacity of 200,000 lbs., and is adapted to take in tension specimens up to 8 ft. in length, transverse specimens to 10 ft., compression specimens to 4 ft., and specimens in sheering, bulging, punching and torsion to the 200,000 lbs. capacity, the smallest reading on the beam being 10 lbs. The auxiliary machine is adapted to making tests in tension and compression up to 2 ft. in length, and has a capacity of 10,000 lbs., and reads to $\frac{1}{2}$ lb. Thus it will be seen that the apparatus is susceptible of doing work of all kinds up to its maximum capacity. Should a specimen of wire be presented, it may be tested in the auxiliary part of the apparatus to a half-pound, rapidly and easily, while if the next specimen be a 15-in. I-bar, 10 ft. in length, it may be placed on transverse blocks of the large machine and broken in a few moments. The general features of the machine being here illustrated, a more complete idea may be obtained by reference to the following cross-sections: the first one being taken longitudinally through the center of the machine, and the second transversely through the main levers of the scale system. The cast iron legs supporting the platform will be seen here in side elevation and in cross-section, the main levers c and c hang from the ends of these I-beams, supported by two cast iron blocks placed over the swinging bearing pivots from the loops suspended by pins placed through these blocks. The ends of these main levers may be seen to be attached to the two center levers e and e', whereby the stress is conveyed to the end of the testing machine, and to the two multiplying levers previously alluded to, and thence to the weighing beam. Directly under the I-beams, supporting the scale may be seen a secondary frame-work, carrying the screws with their appropriate worm-gears. By means of the main shaft l, with its system of gearing, the worms meshing into the worm-gears at the base of the screws may be rotated. The power is derived from the belt l', which derives a counter shaft set directly over the main shaft l. By means of the gears on the shaft, several different speeds may be obtained according to the judgment of the operator as he may deem it best to apply the stress to the specimen rapidly or slowly. Directly at the right of these multiplying gears is a system of reverse gears very similar to those employed in a large engine lathe. A lever at the side of the testing machine enables the operator at pleasure to reverse the direction of rotation of the main screws. The worm-gears and main screws are cut respectively right and left-handed, so that the friction of one neutralizes that produced by the other, and all tendency on the part of the piece to twist or get out of order is thereby avoided. On the pivot c of the main

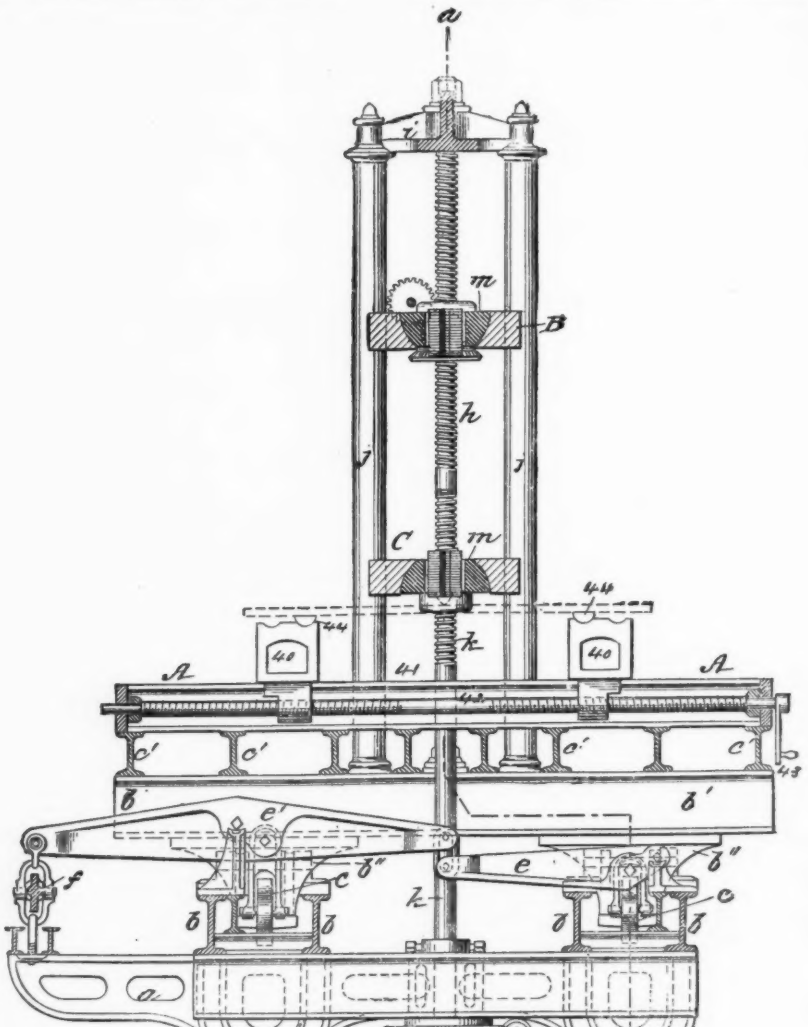


FIG. 9.

levers there stand two castings b^2. These support frame-work of I-beams b^2 that forms the platform of the testing machine. On these I-beams stand a second set of beams, c', and also the columns j and j that support the castings from which hang the adjusting screws H. The object of these secondary screws is

to form a means of rapidly and conveniently adjusting the machine to all the lengths of specimens. For example, the piece in the machine may be 8 or 10 in. in length. At the completion of the test on this piece a bar 5 or 8 ft. will be the next in order. To make the main screws long enough to accommodate such a variety of length of specimens, would require them to be made too heavy, in order to insure sufficient stiffness for preventing lateral vibration. By means of the crank and bevel gears on the upper cross-head, this part of the machine can be rapidly raised and lowered so as to make the different adjustments with great speed. As the upper cross-head hangs on the screws H, they are always subjected to tension, and the compressive reaction comes on the platform by means of the columns *j* and *j*.

In this machine, while strict attention is paid to the relative centering of the cross-heads, there is a device to make the testing machine automatically self centering, so that any possible error in the setting of the specimen or in the alignment of the machine may be corrected by the apparatus itself. It will be noted that the cross heads *b* and *c* are extremely large and are provided in the center with a spherical socket. In this socket there stands a segment of a sphere, carrying the wedges for gripping the test piece.

Let it be supposed that the specimen is placed in the machine eccentrically. As soon as any application of stress occurs the piece swings, and moving the spherical segments in their sockets, adjusts them so as to render the axis of stress coincident with the axis of the piece. The spherical sockets are lined with an anti-friction metal, and the spherical segments are of polished steel constantly lubricated. As a result, the coefficient of friction falls as low as about 5 per cent., and the weight of the segments being less than 200 lbs., the total cross stress that could come on any piece previous to the movement of the segment is about 10 lbs. Inasmuch as the specimens to be tested in these machines will always rise nearly, or up to, 100,000 lbs., this possible cross strain of 10 lbs. can be regarded as an error not large enough to take into account. The facility with which tests in other stresses may be made can be readily understood from the examples in compressive and transverse stress. The two anvil blocks 40 slide on the screws 42, and then the I-beams A may be readily and quickly run in and out by means of the crank 43, so as to adapt the testing machine to any length of span either equal or unequal from the center of the cross-heads. On the top of the anvil blocks the piece for transverse examination is placed, resting on the jaws 44, which are semi-cylindrical pieces of hardened tool steel. The object of these jaws is to facilitate the deflection of the test piece under stress. Right under the cross-head *c* a triangular nose iron is placed, which, by the action of the cross-head, is depressed and brought on the top of the transverse specimen. As fast as the piece deflects the jaws 44 swing in their sockets and adjust themselves to the constantly increasing depression of the piece, swinging around their center and so preserving a uniform length of span, while a broad bearing is constantly maintained under the test piece, and any tendency to cut at its edges is thereby avoided. Simply removing the transverse specimen, a compression test may be made by placing under the cross-head *c* a heavy iron plate for the reception of the specimen, and continuing the downward motion of the cross-head. It will thus be seen that the changes from long to short specimens, and from one kind of stress to another may be readily and easily made in this form of testing machines, requiring only manipulation enough simply to introduce the piece to be tested in its appropriate place, while the machine itself is constantly ready for any of the different forms of stress. The same may be said of the appliances for shearing, bulging, punching, torsion and the like.

The platform of the machine, as has already been stated, has considerable size, and when the machine is built each lever is sealed separately, that is, the lever is hung up from its fulcrum, and standard weights are placed on the pivots, and the distance between the edges slightly varied until these weights exactly balance each other. After the machine is erected in place, standard weights are piled on the platform, and every graduation on the beam is adjusted

to the weights previously placed on the platform. It is obvious that the accuracy of the machine is not dependent on the calculation of lever ratios, or on any alteration in the parts of the testing machine, but inasmuch as the platform gives sufficient size on which to place any desired number of standard weights, the machine can at any time easily and inexpensively be proved to be either right or wrong; in fact the weighing of oneself on the testing machine by simply stepping on the platform is a simple, accurate, and very expeditious mode of making an examination of this kind. Regarding the sensitiveness and the accuracy of the lever system of testing machines, the following experiments may be quoted as derived from actual practice:

A machine, similar to the one illustrated in Fig. 8, has been constantly in use in the "Department of Tests and Experiments" for the past two years. The following experiment was made within a month: When the machine was entirely unloaded, weight of $\frac{3}{4}$ lb. of the platform caused the beam to rise promptly. A test piece was then introduced into the machine, and 100,000 lbs. placed on the platform, when a weight of 6 lbs. caused the beam to move equally with the original $\frac{3}{4}$ lb. Inasmuch as this machine has been subjected to the wear and tear of all sorts of tests, it may be considered that a weight of 6 or 7 lbs. is probably its maximum error, even under the most severe loads. The least reading on the poise of the beam in question is 10 lbs. so that its sensitiveness and accuracy are within about 60 per cent. of the least reading on the beam; consequently if all coefficients of friction and inaccuracies of mechanical construction are eliminated within half the smallest beam reading the machine may be considered practically correct. Again, with regard to what extent it is desirable to carry the accuracy and sensitiveness of a testing machine, it will be generally conceded that engineers rarely care for anything in full-sized pieces beyond the hundredths place of figures. There are few lathes in the country that may be relied upon to turn a test piece perfectly round. There are fewer men who, with a tool capable of such extreme accuracy, have the skill of manipulation sufficient to produce a perfectly round piece, and there are still fewer gauges whose delicacy and accuracy are sufficient to measure a test piece of an inch or more in diameter to an error less than a thousandth of a square inch. Now, if it is impracticable to measure the area of the test piece less than one thousandth of a square inch, which in iron corresponds to a variation in the testing machine of 50 lbs., and in steel to a variation of 80 or 90 lbs., and if the testing machine reads to $\frac{1}{8}$ or $\frac{1}{10}$ of the possible error of measurement in the test piece, is it not more desirable to direct endeavors to a more accurate gauging, rather than to a refinement of the weighing capacity and sensitiveness of the testing machine? Of course, in making experiments on turned or machined test pieces, accuracy of measurement and of weighing are both desirable, but the knowledge to be derived from such test pieces is simply the knowledge of the character of the material of which the piece consists. While the quality of the materials is a very important item, the consideration in the design of a structure the actual strength of the various members employed is, to the practical engineer and architect, of far greater importance. To cut a piece out of the center of an I-beam and to break it in a testing machine may give the investigator a knowledge of the material of which a beam is composed, but when it is wished to know what load may be safely put on that beam when placed on the floor of a building, it is necessary to know the actual strength of the beam as a whole, and not the theoretical quantity obtained by calculation from a test piece, broken under circumstances entirely different from those which occur in actual use of the beam. Consequently the information desired at the present day is of the actual strength of members employed in construction, just as they are used, rather than that of carefully prepared test pieces which are broken under especial circumstances.

The difficulty of measuring a test piece increases about as the square of its size. If the piece be carefully machined, the errors of measurement may be estimated to be from $\frac{1}{1000}$ to $\frac{5}{1000}$ of a sq. in. per inch of area, while if bars direct from the mill are to be experimented on, the errors induced by variations in rolling, by flaws, seams and inequalities, by oxida

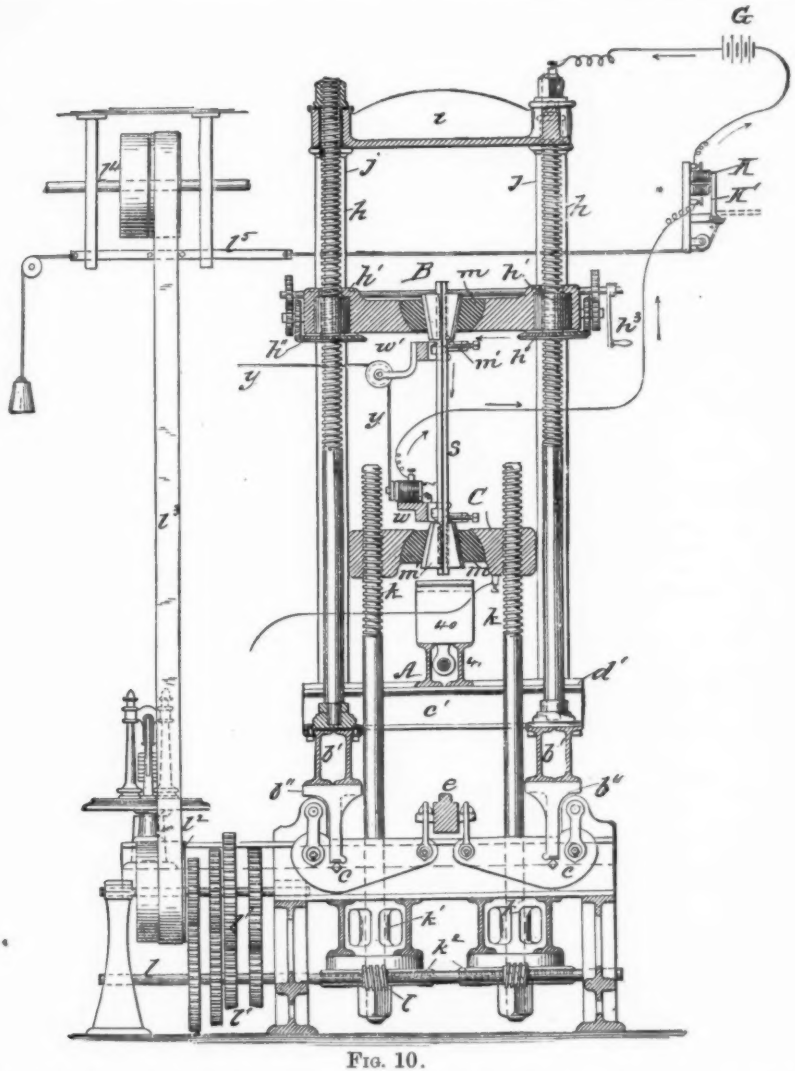


FIG. 10.

tion and scale on the piece, may arise to an extent so large, that in I-bars of from 4 to 8 square inches in area there may be an error of $\frac{5}{1000}$ or $\frac{8}{1000}$ of a square inch. Thus, a possible error in the measurement of the test piece corresponding to from 2,500 to 4,000 lbs. may be introduced; consequently, if the testing machine is reliable to 25, 50, or even 100 lbs., and the error in the measurement of the test piece may amount to 10 or 20 times that quantity, the refinement of the testing machines seems to be hardly so much desired as refinement of measuring facilities.

One of the largest items of expense in making tests has been the necessity of carefully preparing each test piece to adapt it to the jaws of the testing machine. In many machines

it has been necessary to select a piece considerably larger than was desired, and turn or plane it in the center so as to secure it to the testing machine. In fact, some specimens not long ago tested on one of the Rodman machines in Washington, the author was informed that some small test pieces of steel about 2 in. long and half an inch in diameter cost $10 each, simply to prepare them to be placed in the testing machine. This large item of expense has a very depressing effect upon the tendency to make experiments on the strength of material. The machine now under consideration has been specially planned to take in sections of any shape whatsoever in original size, so that those desiring to make experiments on real shapes, such as I-beams, channels, stars, and even railway rails, can simply cut a piece off the bar in question, send it to the testing machine, have it broken without the necessity of any machine work.

The spherical sockets previously alluded to for suspending the gripping wedges have four sides. These sides are inclined to the axis of the machine at an angle of about 12 degrees—two of them being curved and two of them being straight. By means of a series of wedges having curves and straight backs, pieces of any section whatsoever may be placed in the testing machine and completely surrounded by the gripping wedges, so that the stress of the testing machine is firmly and equitably distributed over the entire test piece. Of course this applies simply to tests made in tension, while it will be perceived that transverse and other tests may be accomplished by similar contrivances.

Referring to Fig. 10 (the cross-section of the machine), it will be seen that the battery G is attached to the top of the adjusting screws HH. These screws are carefully insulated from the rest of the machine by standing on rubber bases and passing through rubber bushings held in the interior of the top casting, consequently these screws, with their corresponding cross-head, are electrically insulated from the rest of the testing machine, and being joined to one pole of the battery, form the only means by which the current can flow into the machine itself. As soon as the test piece is connected with the top cross-head it becomes thereby connected with the battery. On the lower end of the specimen may be seen a small clamp carrying an electro-magnet. One end of the wire of this magnet is in connection with the specimen, while the other end of the wire is joined to a little binding screw on top of the magnet, to which the other pole of the battery is attached, so that the current actuating this magnet flows through the test piece under examination. A magnetic clutch M, for holding the driving belt on the tight pulley, is also included in this part of the battery circuit. As long as the specimen remains intact, the current flowing from the battery, excites the two magnets and attracts their armatures. When the rupture of the test piece occurs, the current is at the same instant broken, the magnets are demagnetized, the magnetic clutch M is released, the belt slides, by means of a counterpoise weight, to the loose pulley, and the testing machine stops. On the top of the specimen nearest to the upper cross head is attached a second clamp, carrying a small sheave or pulley. Around this pulley, parallel to the specimen and attached to the armature of the lower clamp magnet, passes a flexible steel tape y. Referring to Fig. 11 an enlarged view of the specimen and clamp with its magnet may be seen. Here it will be noticed that the tape, after passing alongside the specimen, runs down to a pencil, or stylographic pen that is held in a carriage, placed over a metal cylinder carrying a sheet of cross-section paper. It is at once obvious that as fast as the specimen elongates under the action of the stress, the pencil is drawn along the cylinder parallel to its axis. This axis (the axis of x in analytical geometry) is assumed to be the axis of elongation. Inasmuch as the cross-section of the tape is very large in comparison with the friction of the pencil carriage and the supporting pulleys, the tape itself is subjected to comparatively little stress, and is always kept tight and in its place by means of the counterpoise weight y'; consequently, every deformation of the specimen is accurately recorded on the cross-section paper by a corresponding motion to and fro of the pencil. In actual practice it may be said that the record of the cross-section paper corresponds within $\frac{1}{100}$ of

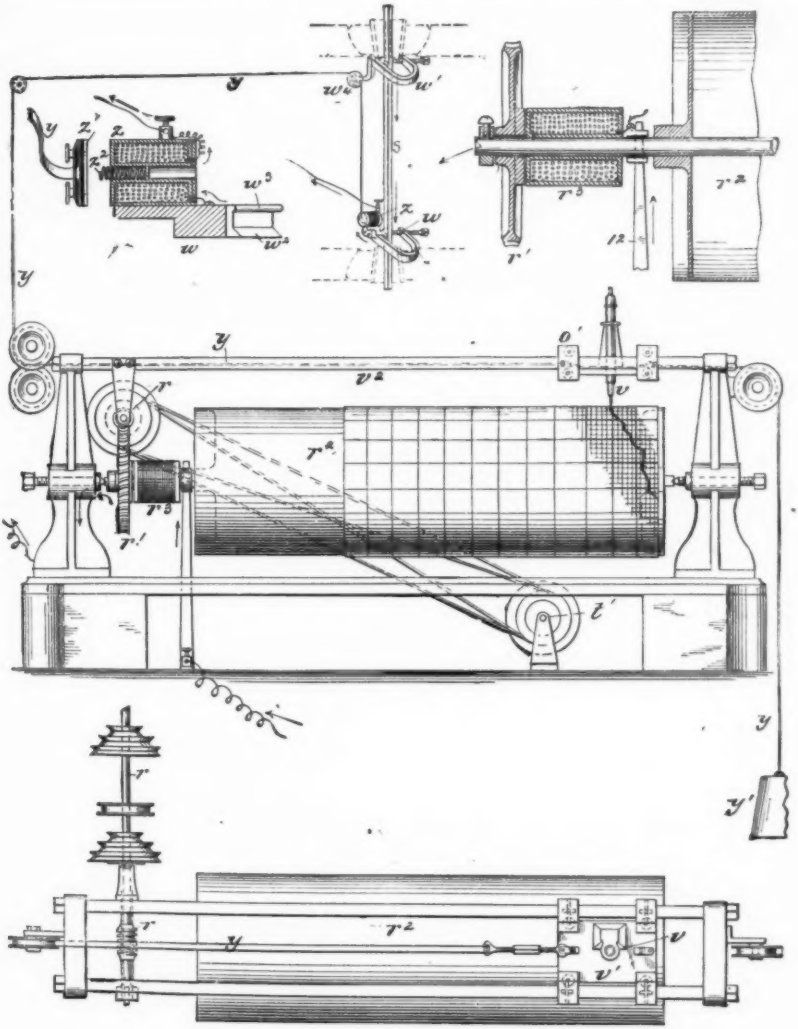


FIG. 11.

an inch to the elongation measured on the specimen, and this for ordinary experimental work is sufficiently near. It will be noticed that the clamp is supplied with a spring and screw *w*. These screws are employed for securing the clamp to the specimen, and the spring serves to take any reduction of area caused by the drawing down on of the piece, and to constantly keep the clamp tightly secured in its place. Nearest to the magnet the side of the clamp is supplied with two edges, one rounded and one sharp. The sharp edge slightly indents itself into the specimen and secures the clamp rigidly into its place, while the round edge forms a zero mark from which the percentage of stretch may be readily calculated. The top clamp is made in a corresponding manner, and the sharp edges are placed next to the jaws of the cross-heads. Consequently it is very

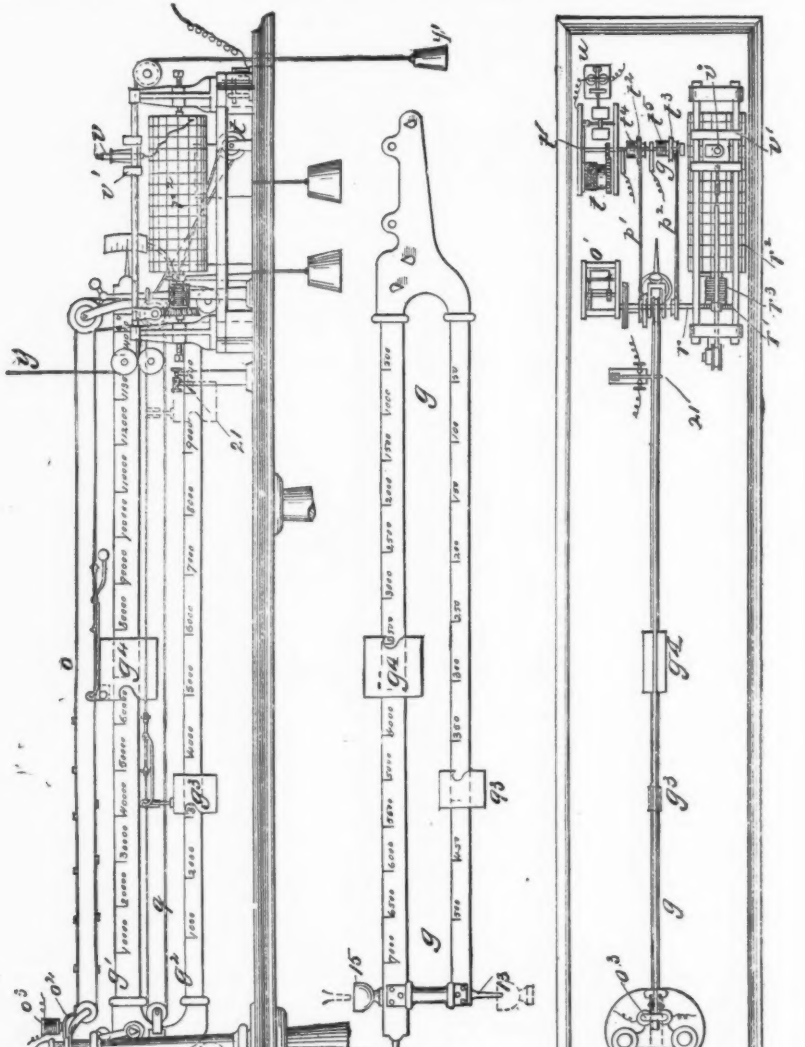


FIG. 12.

rare that a specimen can break outside of these edges, and they then form data marks of reference, from which the deformation of the specimen may be calcu-

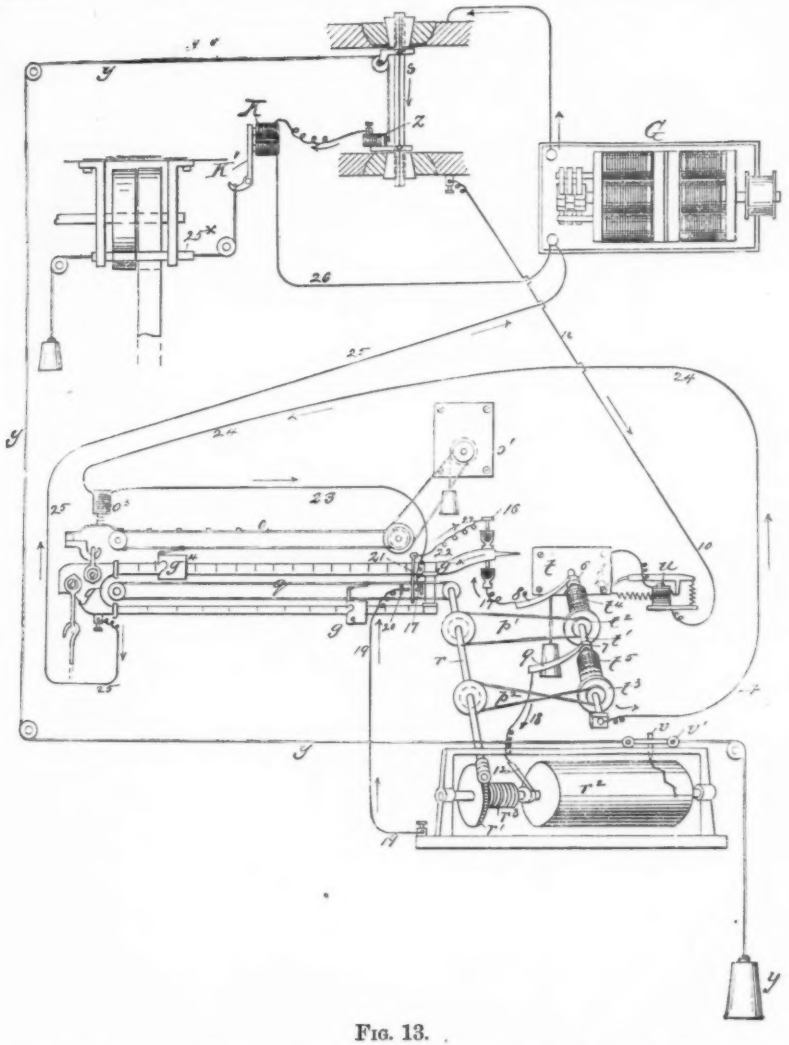


FIG. 13.

lated. The autographic record of the deformation of the specimen is by this means made plain. It now simply becomes necessary to record, at the same time the stress producing the deformation. Turning to Fig. 12 an enlarged view of the beam with the registering cylinder may be obtained. From this illustration it is perceived that the beam is composed of two parts, a top bar and a ower bar, each carrying its appropriate poise. The large poise is ten times as heavy as the small one, consequently the small one must move ten times as far as the large one to produce a corresponding effect on the scale. The entire travel of the small poise is equivalent to a weight of 10,000 in the testing machine, while the entire travel of the large one is equivalent to the entire capacity of 200,000 lbs. On the end of the beam will be seen two mercury cups 16 and 17. The skeleton

view of the beam with its apparatus shown in Fig. 13 may perhaps render this operation a little more obvious. From the lower cross-head of the testing machine, connected with the specimen, the electrical current flows into the butt of the beam. The two mercury cups at the end of the beam are so arranged that when the beam is in the center neither cup is included in the electrical circuit which is consequently broken. If the force on the platform increases, the beam rises and the upper cup is brought into circuit and the current flows. Should the weight in the testing machine decrease, the beam falls into the lower cup, and the electric circuit is also completed by the drop of the beam. The lower poise is connected by means of the steel take with a little countershaft r. This countershaft is joined by an open and closed belt to two magnetic clutches t^4 and t^5. These clutches are placed upon the shaft that is driven by the clockwork t. When the beam rises, the magnetic clutch t^4 is excited by the completion of the circuit through the mercury cup 16. As a consequence the small poise is immediately drawn out along the beam, tending to rebalance it. Should the motion of the poise equal the weight on the platform, the beam then sinks to the center, the circuit is broken, and the poise stands still. If, in any case, the force on the platform decreases, the beam drops into the lower cup, the magnetic clutch t^5 is excited, the cross belt p^3 begins to move, and the poise is moved backwards on the beam, tending again to rebalance it. Returning to Fig. 12 a switch will be seen at 21, so placed that when the small poise reaches the maximum extent of its travel it strikes against this switch and automatically closes the electrical circuit through the magnet o^3. The effect of this circuit is to excite the magnet, release the large poise g^4, and cause it to move out $\frac{1}{10}$ of the travel on the top beam, which is exactly equivalent to the total travel of the small poise on the lower beam. Instantaneously with the motion of the large poise the beam, superweighted, drops, closing the circuit in the lower cup and returns the small poise to the butt of the beam. It is plain that the rise and fall of the beam absolutely controls the motion of the poises, as the beam forms an automatic shunt for so circulating the electric current as to cause the poises to move to and fro. This motion of the beam is entirely dependent on the pressure exerted on the platform, so that a piece being placed in the testing machine the weighing may be done by the machine automatically in a way far more sensitive and accurate than is possible to accomplish by any hand labor however skilled.

In order to accomplish the registration of the motion of the poises which is all that is necessary to record the stress on the specimen, the cylinder previously mentioned is magnetically connected with the shaft r, so that as fast as the poises travel out, a worm-gear connected with the magnet on the cylinder causes the cylinder to revolve circumferentially, thus making the axis of y the axis of stress. The motion of the pencil, as previously has been shown, records the deformation of the specimen, while the motion of the cylinder records the motion of the poises. By so proportioning the pitch of the worm-gear that an inch on the circumference of the cylinder corresponds to a definite number of pounds on the testing machine, it becomes an easy matter to read from the motion of the cylinder the amount of force which has been applied to the specimen, consequently the curvelinear line that is marked on the cross-section paper by the combined motion of the pencil under the influence of the tape and of the cylinder, gives a record whose abscissæ and ordinates are measures respectively of the stress to which the piece is subjected and the resulting strain. As soon as the piece breaks, the current which actuates both the motion of the testing machine, the motion of the tape and the motion of the cylinder is ruptured. The machine stops, the poises stand still and the pencil comes to rest, leaving the record on the cross-section paper for any future inspection.

The preceding method of obtaining autographic diagrams possesses many advantages for adapting it to testing machines that are to be built especially compactly. There is another method of obtaining the same results, whereby the registering cylinder may be located at any distance from the the testing machine. in Figs. 14 and 15 are two photo-engravings from the beam and the registering cylinder employed in the "Department of

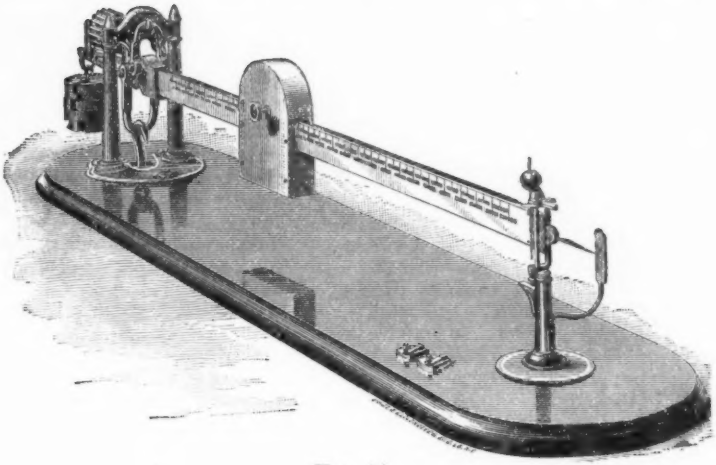


FIG. 14.

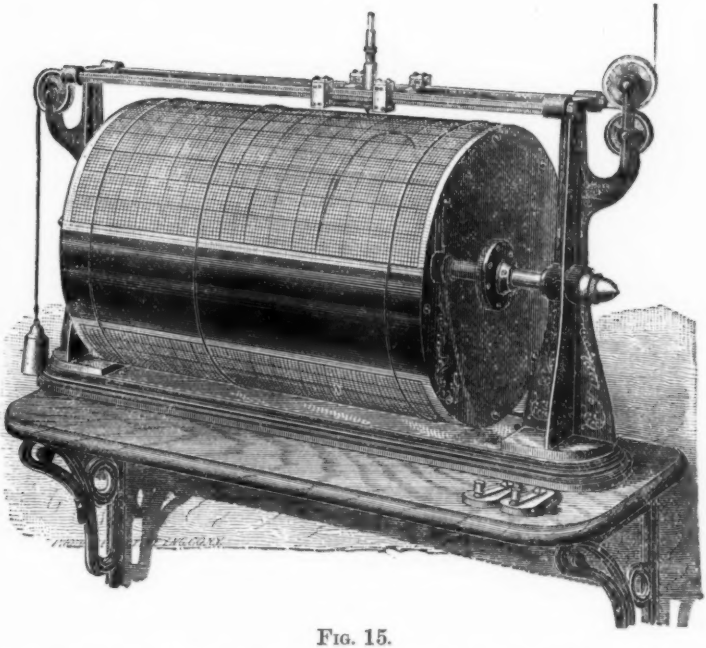


FIG. 15.

Tests and Experiments." In Fig. 14 it will be seen that the beam consists of a single bar suspended on a stand at one end and enclosed in a guard at the other, while on this beam there rests a semi-circular brass box forming the poise. Along the top of the beam, there is cut an exceedingly fine rack and the motion of the poise is obtained by a pinion placed inside of the box and gearing into this rack. At the end of the beam may be seen the mercury cups alluded to in the

former method for making the electrical connection as the beam rises and falls. The operation of this piece of aparatus is substantially as follows: The clock-work motor for driving the poises to and fro on the beam, is connected with the mercury cup by means of some brass strips placed in the rear of the steel bar forming the beam. These strips are connected with two electro magnets on the inside of the poise, consequently when the beam either rises or falls, one or the other of the magnets is excited, the corresponding train of clock-work thrown into action and the poise gradually rolls to and fro until a balance is re-established. This part of the apparatus, that is the accomplishment of the motion of the poise to and fro on the beam, is exceedingly simple. The knotty part of the problem being to correlate the motion of the poise with the motion of the cylinder exactly so that in a given travel of the poise along the beam, the cylinder may move a corresponding quantity. Of course the ratio between the two movements is simply a matter of proportioning so as to accommodate the ordinary cross-section sheet to the circumference of the cylinder, but an exact and constant ratio were very important. To solve this problem was to accomplish the solution of one similar to the autographic telegraph or electric clock and similar pieces of mechanism, but with some peculiar features arising only in this special instance. To go a little more into detail of the poise, there are enclosed in a brass box two large wheels about 8 in. in diameter. The wheel placed nearest the front of the poise is graduated with a series of numbers, corresponding to similar weights in the testing machine. The pinion carrying the poise along the beam is an inch in circumference, and consequently a single revolution of the pinion carries the poise one inch along the top of the beam. The dial wheel is secured directly to the pinion shaft so that there can be no backlash between the two, and being 8 in. in diameter one revolution of the pinion causes the dial wheel to travel 25 in. in circumference. In the testing machine in question, a motion of an inch along the beam corresponds to a weight of 4,000 lbs. in the machine; and the dial wheel being graduated into 400 parts, each graduation corresponds to a weight of 10 lbs. in the machine. The other wheel is constructed in precisely the same manner as the dial wheel, excepting that in the place of the graduated marks there are little strips of india rubber so that the wheel presents a series of teeth, alternately made of india rubber and of brass. On the circumference of this wheel, there presses a brass commutator strip so arranged as to include the cylinder in its electrical circuit. When the poises commence to move along the beam, the teeth, alternately of metal and rubber, move under the commutator strip and with every passage of a brass tooth under the strip, an impulse of electric force is transmitted into the cylinder. In Fig. 15 a detailed view may be seen taken from the working drawing the cylinder. Inside of the cylinder are two toothed wheels, which are mounted on a central shaft and are capable of being ratcheted round by means of the little lever arm and pawl, operated by a magnet placed directly under each of the wheels. One of these wheels is intended to drive the cylinder in one direction and the other in a contrary one. One electro-magnet is connected with a mercury cup on the bottom of the beam and the other with a mercury cup on the top. Consequently, when the beam makes connection with either cup and the beam commences to move, the corresponding electro-magnet in the cylinder is excited, the armature is attracted and commences to ratchet the cylinder wheel around. By means of a series of gears placed at the extreme right-hand of the cylinder, the drum is moved one way or the other in such a proportion that the motion of the poise may be accurately correlated with the motion of the cylinder. If the gears in the cylinder are accurately cut and properly proportioned, and if the armature of each magnet makes one stroke for every tooth on the poise wheel, the cylinder will be moved to an amount that is exactly commensurate with the poise itself. At first it may perhaps seem that so accurate an arrangement would be almost impossible to construct, yet the same obstacle is presented in all machines of precision, but nobody objects to an engineer's transit or to astronomical telescope in consequence of difficulties in construction.

In machines already built it has been found perfectly possible to so correlate

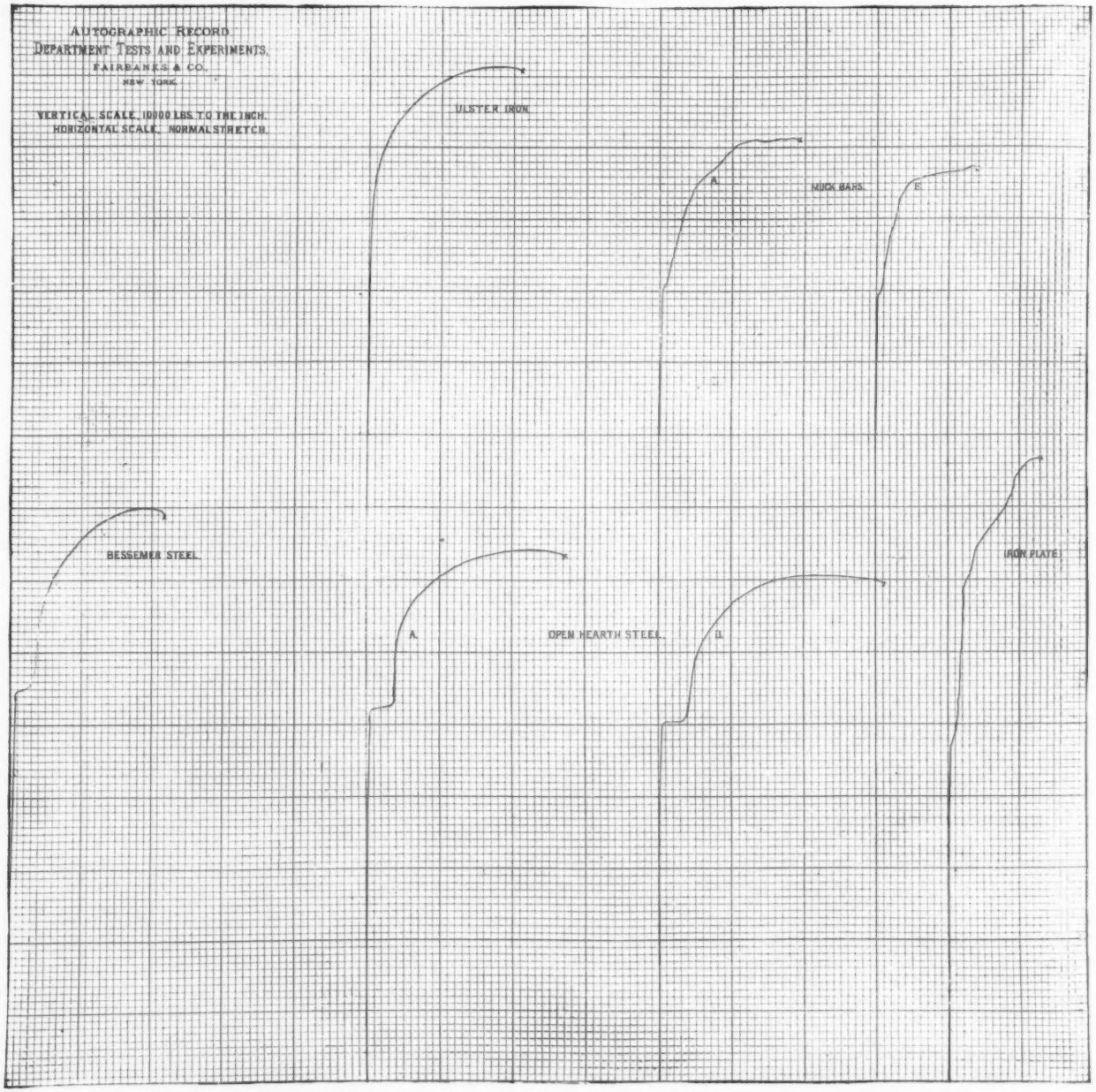

AUTOGRAPHIC RECORD
DEPARTMENT TESTS AND EXPERIMENTS.
FAIRBANKS & CO.
NEW YORK.
VERTICAL SCALE 10000 LBS. TO THE INCH.
HORIZONTAL SCALE. NORMAL STRETCH.
ULSTER IRON.
A.
NUCK BARS.
E.
BESSEMER STEEL.
A.
OPEN HEARTH STEEL.
B.
IRON PLATE.

FIG. 17.

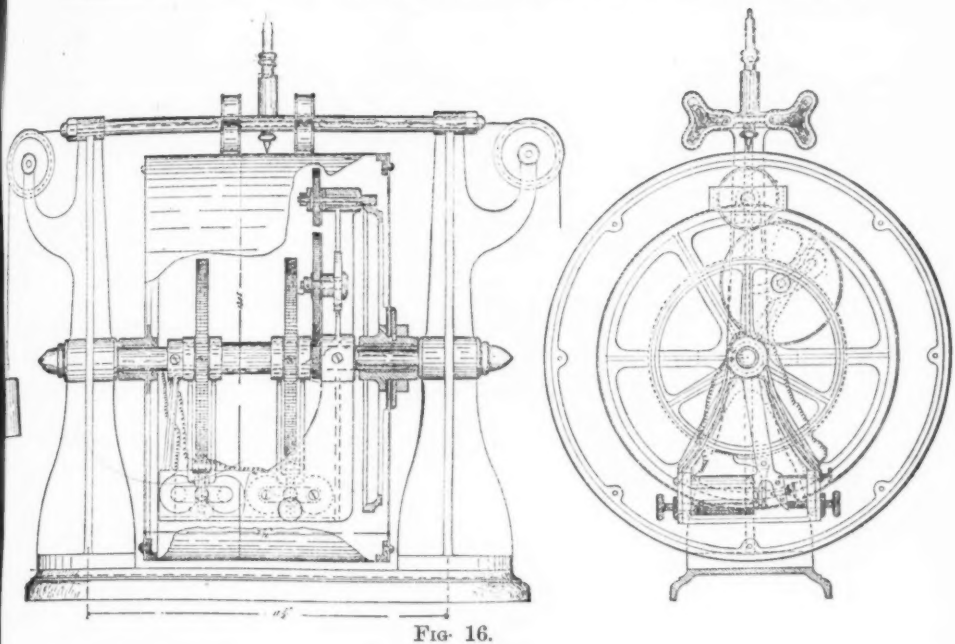


FIG. 16.

the motion of the poise with the motion of the cylinder that in the entire travel of each one, there should be a discrepancy between the two of less than 1-100 of an inch.

If the strip of cross-section paper on the cylinder be 40 in. long giving a stress of 4,000 lbs. to the linear inch, 1-100 of an inch corresponds to 40 lbs. This is about as fine a reading as can practically be made on cross-section paper, and as it is 4 times as large as the smallest reading of the poise it is obvious that this error of 1-100 of an inch on the entire travel of the cylinder is too small to be of any practical value.

Over this cylinder is a track carrying a little carriage and pencil connected with the specimen by means of a steel tape, in a manner similar to that previously described. The cylinder and the poise are only connected, in a manner similar to the connection existing between two telegraph stations, consequently, if desired, the cylinder may be placed in one locality and the testing machine in another, so that it is perfectly possible for the cylinder to be entirely exterior to the control of the operator manipulating the testing machine.

Fig. 17 gives a photo-engraving taken from a sheet of cross-section paper bearing a half dozen of the curves autographically drawn by the testing machine. In this illustration the cross-section paper has been ruled in feet and decimals of a foot, and each of the specimens were one foot between the stretch clamps; consequently the percentage of stretch of the specimen may be at once read from the cross-section paper. The lower half of the sheet contains three steel curves which it will be readily seen, bear to each other a strong family resemblance. The curve commences with a straight line slightly inclined to the axis of stress at a constant tangent of one whose equation may be described as $y=ax$. When the elastic limit is reached a sudden point of inflection occurs, the tangent swinging around and becoming nearly or quite parallel to the axis of strain. Very soon, however, a second point of inflection makes its appearance, and the tangent nearly returns to its former inclination and the curve takes on a general parabolic form. These steel curves as well as the curve given by the specimen of Ulster iron may be taken as typical forms of curves to be obtained from a material which is nearly or quite

homogeneous. The lines are quite true and regular, and the curve manifests little indications of non-uniformity in the material. As soon as the maximum stress in the specimen is reached, the material begins to reduce more rapidly at some point or other of its length than the testing machine can keep pace with. Consequently, the stress on the specimen decreases gradually, while at the same time the strain rapidly increases. As a consequence of this, a third point of inflection occurs, the tangent inclining toward the axis of strain, and changing from a positive to a negative value. This proceeds until the specimen is ruptured and the apparatus comes to a stand still.

The other three curves given here were made by a piece of boiler plate and two specimens of muck-bar. These are exceedingly good illustrations of the value of the autographic method. It is well known that both boiler plate and muck-bar are decidely non-homogeneous, and as a result here the curves are exceedingly irregular, especially after passing the elastic limit. While a general resemblance may be traced to the preceding ones, they are full of points of inflection, and would seem to indicate that the material, being made up of fibres which were alternately elastic and brittle, was ruptured by the continuing action of the stress in the testing machine, breaking one fibre after another, in very much the same way that a rope or cable is parted. To give a general record of a test it is believed that the autographic method is without parallel. As here described, however, it is not sufficiently accurate for careful investigation, into the limit and the modulus of elasticity. For instance, it is impossible to read on the cross-section paper nearer than about 100th of an inch, and as any arrangement to magnify the stretch up to the elastic limit would so increase the elongation after passing that point, as to extend the curve beyond the capacity of the cross-section paper that is of an ordinary sheet. The autographic diagram will give the elastic limit within 1000 lbs. per square inch of cross-section and the modulus of elasticity within 100,000 lbs. Yet for many purposes it is desired to obtain a more accurate approximation to these quantities, and in Fig. 18 may be seen an illustration of a piece of apparatus devised by Col. William H. Paine, of the East River Bridge, and used by him there in the investigations of the steel to be used in the trusses. It will be seen that the apparatus consists of two steel bars a and b, so arranged as to slide parallel to each other. At the ends each bar is supplied with a knife edge, f held in the sliding piece of brass m, which may be adjusted at any end of the bar. By means of these knife edges the whole apparatus may be clamped to the specimen by the use of the springs g. On the bar a, a small steel projection o, bears against one of the knife edges of the multiplying lever e, and the other end of this lever comes in contact with a supplementary vernier and scale d, e. Now as the piece under examination elongates, the bars move by each other, the multiplying lever e turns on its fulcrum, pushing the vernier d outwards along its scale. Thus it is obvious that the whole apparatus after being placed on the specimen works entirely without any intervention from the operator..

In the case of micrometer screws it becomes a pretty difficult matter for the same person to make readings twice alike, on account of the varying coefficient of friction and of the varying personal equation. And again the operation of making a reading with micrometer screws is exceedingly slow, and should, as in the hydraulic machines, the pressure have any tendency to relax, it is almost impossible to obtain a correct reading, whereas in the gauge in question the reading may be made as fast as the eye can gauge the coincidence between the vernier and the scale. In fact, in making many thousands of tests in the East River Bridge, at the Cambria Iron Works, the author used this instrument, and employing one man to place weights upon the beam of the testing machine, was accustomed to sit where he could see the vernier of the stretch gauge, and the moment that the beam raised to catch the reading on the scale, so that the entire operation of making a test on a bar one foot long, and an inch square, included the taking of some 20 to 30 readings, did not occupy a time of more than 8 to 10 minutes, which is a speed never to be obtained by any arrangement of micrometer screws. By means of the extension piece and clamp l and m, the sliding bars of this apparatus may be ex-

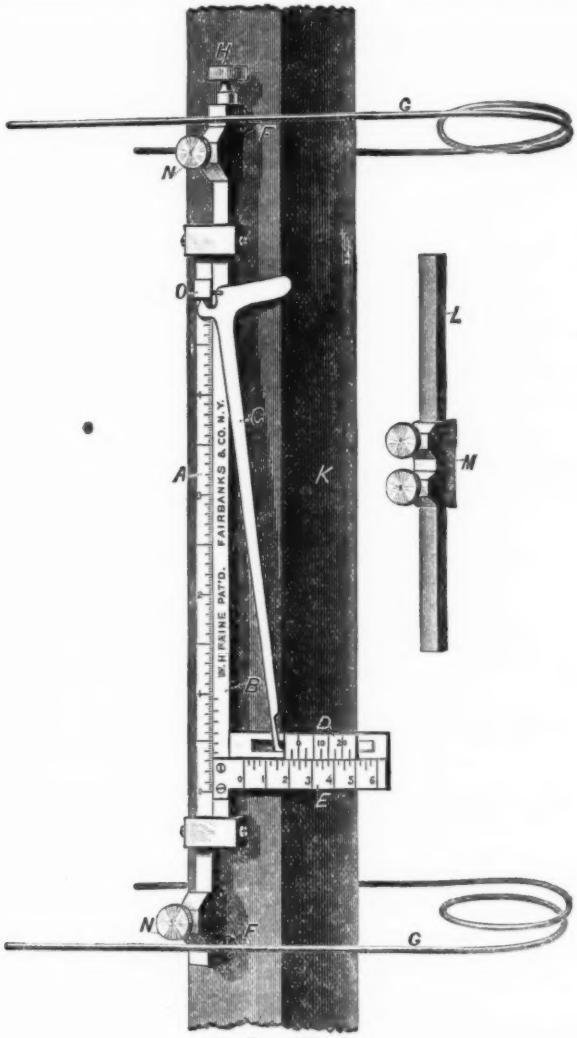


FIG. 18.

tended to any entire length, and by this means it becomes an exceedingly valuable instrument in the investigations of stress which occur in structures already existing, such as bridges, roofs and the like. As a case in point may be mentioned an examination made by the author at the opening of the new cantilever bridge at Niagara. Two gauges were employed at the test of the cantilever bridge, vernier *a* being screwed to a tie-bar of the truss extending over one panel, and vernier *b* attached to the bar extending over two panels from the anchorage end of the cantilever on the American side. Vernier *a* extended over a distance of 4.75 feet, and vernier *b* over a distance of 5 feet of the bars. Readings taken at the various points at which the loading trains came to a stand, and gave the extensions

produced by a quiescent load, during the movement of the trains, the verniers fluttered a little, showing even at slight speed that there is a sensible effect from the shock, and as a loaded train moved off on the American side there was a negative reading of about $\frac{25}{100000}$ of a foot, showing a slight compression in the tie-bar. The following are the readings of the verniers reduced to a length of one foot of bar:

Train at Canadian abutment,
vernier a $\frac{10}{100000}$.
vernier b $\frac{12}{100000}$
Train at Canadian tower,
vernier a $\frac{74}{100000}$
vernier b $\frac{72}{100000}$
Train at Canadian end of center span,
vernier a $\frac{106}{100000}$
vernier b $\frac{102}{100000}$
Train at American abutment, giving the maximum stress in the rods under examination, . . vernier a $\frac{65}{100000}$
vernier b $\frac{212}{100000}$
Center span entirely loaded,
vernier a $\frac{106}{100000}$
vernier b $\frac{102}{100000}$

Bridge unloaded, verniers returned to zero. Assuming the modulus of elasticity on the eye-bars at 32,000,000 lbs., the following stresses per square inch are obtained from the preceding measurements:

Bar extending from two panels, 6780 pounds per square inch.

Bar extending from one panel, 5280 pounds per square inch.

Thus far vertical testing machines have occupied our attention. With the exception of the Emery testing machine, there are few machines of this class whose points of excellence demand attention.

During the construction of the St. Louis bridge. Capt. Eads built a couple of large horizontal machines, having a capacity of 500,000 lbs. While these machines, however, were superior to anything of the kind at that time, they were not sufficiently accurate to give results which were received with great confidence. They simply consisted of a long heavy framework, carrying a cross head at the one end, with a hydraulic jack, and a pressure gauge attached for straining the specimen.. Consequently the only method of estimating the amount of stress applied was by calculating the pressure per square inch on the ram. As was conclusively shown in experiments with the Watertown machine, the coefficients of friction in the jack are constantly varying, sometimes introducing errors as high as 40 per cent. of the actual stress. Several long horizontal testing machines have been built by the Riehle Bros. for the purpose of making tests of chains, &c. These, however, were of small capacity, rarely rising over two or three hundred thousand pounds. One of the oldest horizontal machines of large capacity is that used in the Washington Navy Yard for investigations on chain cables, and with which all of the preliminary work of the U. S. Board to test iron and steel was made. This machine consists of along horizontal framework of masonry, carrying a hydraulic jack on one end with a scale at the other composed of two levers. On the extremity of the second lever there hangs a large platform upon which a series of weights may be piled as fast as the stress upon the specimen increases, due to the action of the hydraulic jack. Of course this machine is laborious and cumbersome to manipulate, on account of the large number of heavy weights that have to be actually lifted and piled on the platform of the scale.

In Fig. 19 may be seen an illustration of a large horizontal machine which has just been constructed by Messrs. Fairbanks & Co. for the Edgemoor Iron Co. This machine consists of a long horizontal framework of wrought iron channels, upon which travels a hydraulic jack, carrying a three-piston pump, and driven by a belt supported on two idlers at the end of the frame. To accommodate the different lengths of specimens the jack can be run to and fro along the frame at pleasure, and be secured by means of 4 heavy steel pins which pass directly through each of the four columns composing the frame, between the parts of which run steel legs connected rigidly to the jack. A system of valves on the jack provides for the admission of fluid on both sides of the piston, so that the jack may be used either in tension or compression at the pleasure of the operator. At the front end of the testing machine there stands a large bed plate of cast iron, to which the columns are attached, and which also supports the weighing

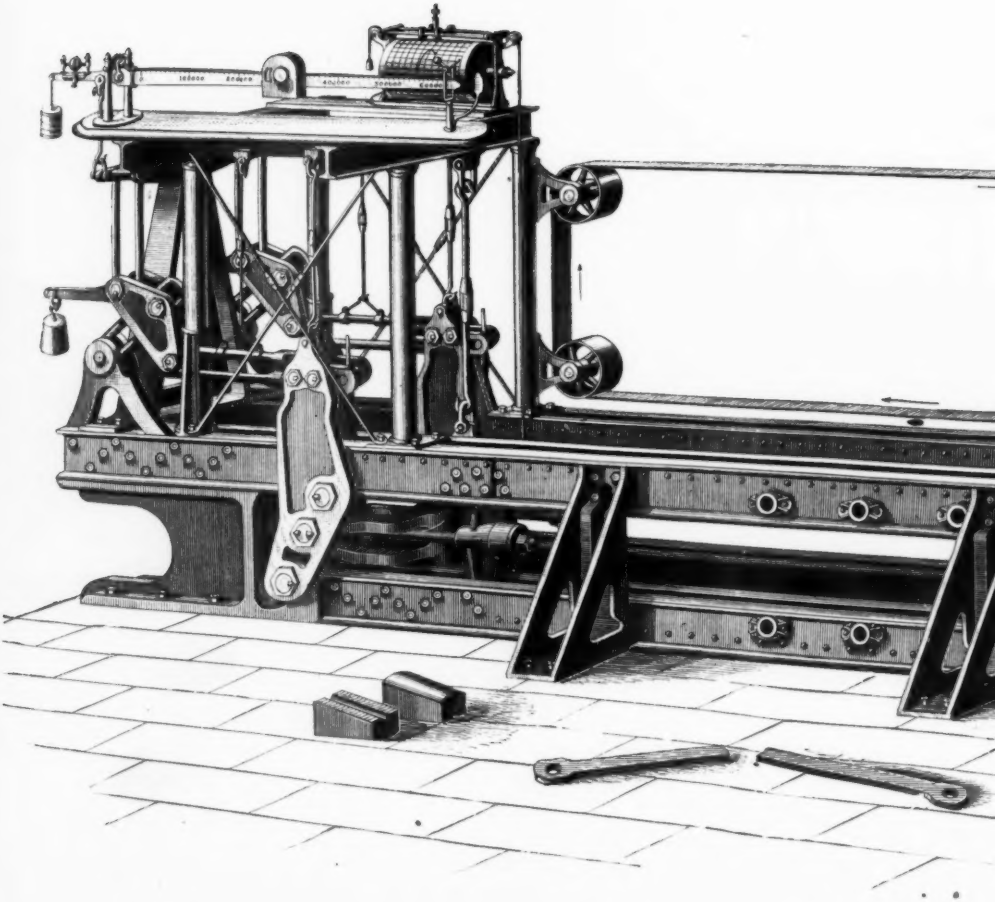
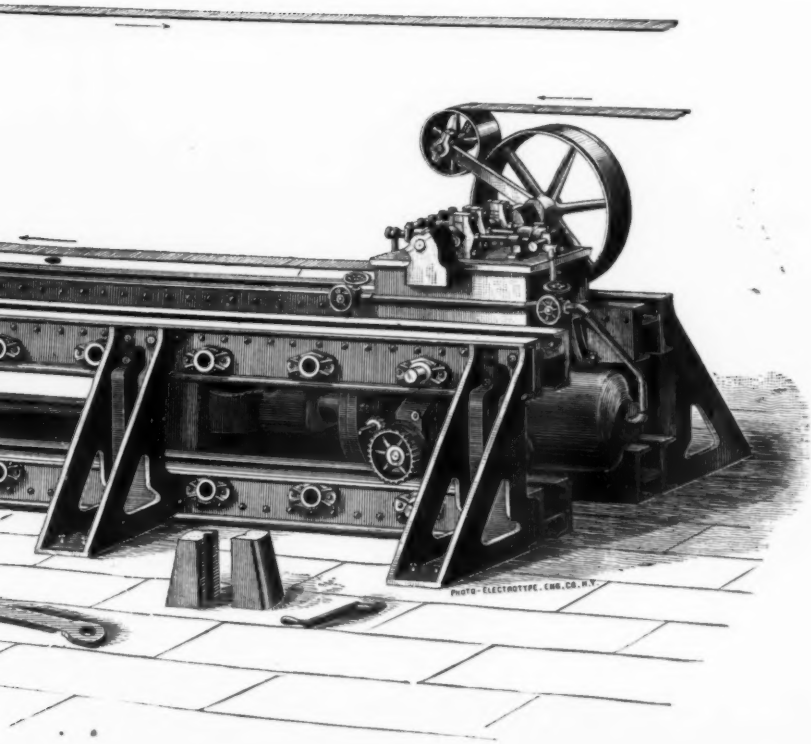


Fig 19.



9.

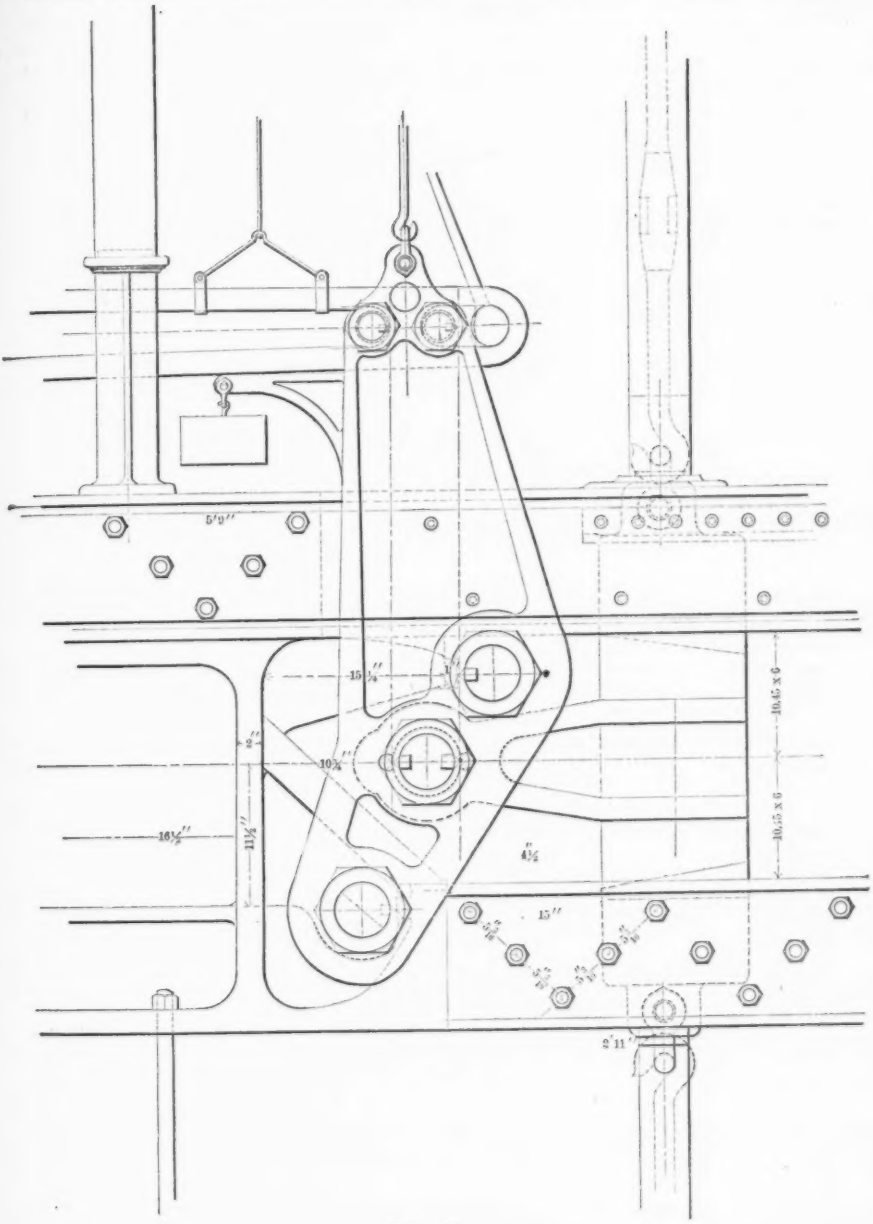


FIG. 20.

mechanism for estimating the stresses. This mechanism consists of two heavy levers hung from the framework of I-beam, so as to swing directly in front of the cross-head of the jack. On the center pivot of these levers there is hung a

second cross-head for the reception of the other end of the test piece. By means of two horizontal links these levers are attached to two knee levers for transforming the horizontal stress into a vertical one and carrying it to a differential lever which conveys it directly to the beam. The beam in this machine is an autographic beam, and the registering cylinder may be seen just behind it. The principal feature of this machine, which is different from those heretofore described, is the ease and facility with which it may be changed from tension to compression and conversely. Inasmuch as the jack is the double-acting one, all that is necessary in the straining mechanism is to alter the position of the valves at either end, so as to change the direction of the fluid in the pumps. The jack being secured to the frame by means of pins passing directly through the columns no change at all is necessary in this part of the apparatus, and the only remaining detail is to arrange the scale system so as to weigh, equally, stresses in tension or compression.

In Fig. 20 may be seen an enlarged detail of the main levers, with the device whereby this change is readily accomplished. Here it is seen that these levers are furnished with 5 pivots, the lower one bearing against a projecting toe on the main casting. The center has two edges instead of one and is surrounded by the casting forming the cross-head. The next one bears against a projection issuing from the front of the main casting, while the two on the top of the lever have seats in the link for conveying the stress to the knee levers. Suppose, for example, a piece in tension: as soon as the jack commences operation, the tendency is to pull the lever towards the jack, the lower pivot catches against the toe of the main casting, and the linear motion is now converted into a rotary one around this pivot as a center, and the stress of the jack is conveyed to the knee lever by means of the link joining the two. Suppose the tension piece to be removed and the compression test substituted therefor, the tendency then upon the operation of the jack is to push the main lever away from it, and towards the large casting, $\frac{1}{8}$ of an inch play being allowed between the vertical lines of the pivots; the lower edge moves away from the toe of the casting, and the third edge strikes against its projecting seat. The result, as in the previous case, is to change the motion of the lever into a rotary one around its pivot edge, and the stress produced on the jack is again converted into tension on the link connecting the top of the main lever with the knee lever. or, in other words, when the machine is acting in tension, the main levers are levers of the second class, and when it is acting in compression they are levers of the first class. By proportioning the pivot distances so that the multiplication is in both cases the same, a single set of levers answers both for tension and compression by simply turning down the little eccentric handle shown at the top, and throwing either one or the other of the link pivots into play. This machine in question has a capacity of 600,000 lbs. in either direction, and is capable of testing specimens between the first of the cross-heads up to 12 feet in length. A peculiar feature, however, is that the scale cross-head has an extremely large opening, and the framework is entirely open directly behind it, so that eye-bars or tension pieces of any length may be easily tested. If, for example, it is wished to test an eye-bar 40 feet long, the bar is introduced through the opening in the scale cross-head and the eye screwed to the cross-head of the jack, while the metal of the bar is gripped by means of wedges placed in the scale cross-head. That this is a fair test and gives all the information to be obtained from a testing machine of much longer dimensions will be readily seen from this fact: First, if the material of a bar is to be tested it can be done equally as well in a length of ten ft. as in a length of 40 ft., and if the construction, method of formation, or proportion of the eye is to be tested in relation to the bar, this is secured by the presence of one eye attached to the cross-head of the jack. Should it be desirable to test both eyes of the bar, this can readily be done by first breaking one and then turn the bar end for end and breaking the other one. Of course, this double test of a single bar requires a little more time, but to compensate for this the space occupied by the machine, the expense of construction, and the labor of manipulation, are reduced to an enormous extent.

REPORTS OF ENGINEERING SOCIETIES.

AMERICAN SOCIETY OF CIVIL ENGINEERS, February 20, 1884.—A Paper on Structural Steel, by E. B. Dorsey, M. Am. Soc. C. E., was read. The paper gave the results of an examination by the writer into the subject during two recent trips to Europe. The steel used for structural purposes is called generally in England mild steel, and in Germany, homogeneous iron. Experts in Great Britain generally rely more upon physical tests and the reputation of the manufacturer, than upon chemical composition. The physical requirements are stated, and the manufacturer uses his discretion as to the composition which will answer these requirements. The rules for testing steel adopted by the British Admirality, by Lloyd's Register, and by the British Board of Trade, were given. The tendency among English engineers is to use steel still softer than has heretofore been thought best. Some large builders use nothing in their boilers over 26 long tons tensile strength per square inch, and 25 per cent. elongation in 8 inches. Others advise the use of steel of from 23 to 25 long tons tensile strength, with the same elongation.

American engineers require from 15 to 20 per cent. higher tensile strength than the English. The Siemens-Martin, or open heart steel, is preferred by nearly all experts for structural purposes, the Bessemer steel being principally used for rails. Ship builders are decided in their preference for the open hearth steel. A much larger number of plates would be condemned of the best wrought iron than of steel. Data were given as to loss of strength in steel plates by punching. Steel can be manufactured into much heavier, longer and wider pieces than wrought iron. Steel rivets are used on the Clyde exclusively in riveting steel. The new Forth bridge is to be built of mild steel. The use of mild steel is extending very rapidly in Europe, and has fast superseded iron for structural purposes.

The paper was discussed by members present. During the discussion Mr. Theodore Cooper referred to the conservative stand taken by him in a paper presented to the Society some four years since, and expressed the opinion that at the present time he would feel still more conservative in regard to the use of iron instead of steel for structural purposes, particularly for bridges or similar constructions.

For boilers, for ships, &c., steel has answered very well, but for structures he would be inclined as yet to advise the use of wrought iron. In compressions, in his opinion, steel has not been proved to be as strong as wrought iron, and the necessity for most careful inspection is greater for steel than for wrought iron.

Mr. M. N. Forney referred to the increasing use of steel for rails, for wheel-ties, and for various parts of locomotive machinery. He referred to the record of accidents which showed that some 66 per cent. of accidents in this country are due to derailment, and only 8 per cent due to the same cause in England. In this country the number of broken wheels is very great, and the tendency towards the use of steel for tires is decided.

Vice-President Paine gave details of the methods of tests of steel in use during the construction of the Brooklyn Bridge, and expressed an opinion favorable to the use of steel.

The paper was also discussed by Messrs. Collingwood, Frith and North.

MARCH 5, 1884.—A paper by Hiram F. Mills, C. E., describing the construction of the Pacific Mills Chimney at Lawrence, Mass., was read by the Secretary. This chimney was built by Mr. Mills in 1873, and consists of an outside octagonal shell 222 feet high above the ground, with a distinct interior core 8 feet 6 inches in diameter inside, extending one foot above the top of the outer shell and eleven feet below the ground. The chimney is founded 19 feet below the ground, upon coarse sand, the foundation being 35 feet square enclosed by pine sheet piling. The base is concrete, one foot thick, then rubble masonry of large pieces of granite in cement, this stone work being 7 feet high. Upon the stone work is placed the brick chimney, the outer shaft being at the base 20 feet wide, and at the top under the projecting cornice 11 feet 6 inches wide. This brick work is 28 inches in thickness at the base; at 12 feet in height it becomes 24 inches, which continues 18 feet; then 20 inches for 20 feet; then 16 inches for 40 feet; then 12 inches for 60 feet; then 8 inches to the top. The inside core is two feet thick to a height of 27 feet and one foot thick for the remaining height of 154 feet. The top of the chimney is of cast iron plates $\frac{3}{4}$-inch thick. The horizontal flue entering the chimney is 7 feet 6 inches square. The vertical flue of the chimney is a cylinder 8 feet 6 inches in inside diameter, and 234 feet high with walls 20 inches thick for 20 feet, 16 inches thick for 17 feet, 12 inches thick for 52 feet, and 8 inches thick for 145 feet. The foundations were laid in mortar of Rosendale cement and sand; the outer shell in mortar of Rosendale cement, lime and sand; and the flue walls in mortar of lime and sand.

During the winter of 1873, the flue being 90 feet above the ground, boilers having 452 square feet of grate surface were connected with the chimney with satisfactory results. Between June and September, 1874, the chimney was finished. The approximate weight of the chimney is 2,250 long tons, the number of bricks being about 550,000. The chimney is opposite the middle of a line of 28 boilers, and 210 feet distant from them. It was designed to serve for boilers having 700 square feet of grate surface, burning about 13 tons of Anthracite Coal per square foot of grate surface per hour.

A description was then read of the chimney of the Merrimack Manufacturing Co., at Lowell, Mass., built under the direction of J. T. Baker, C. E., in 1882. This chimney is founded on a ledge of sand stone. The foundation, 30 feet in diameter, is built of granite blocks laid as they come from the quarry. At the surface of the ground there is a dressed granite base two feet six inches in height, laid in clear Portland cement, the remainder of the foundation being in Rosendale cement and sand. Upon this base is placed the brick work consisting of three cylinders, the outside one 28 feet in diameter, 24 inches thick, the middle one 18 feet in diam-

eter 8 inches thick, the core 12 feet inside diameter and 16 inches thick. The middle cylinder is carried up vertically 75 feet 6 inches; the outside ring has a batter of $\frac{4\frac{1}{2}}{100}$ of an inch per foot to a height of 100 feet. At the height of 75½ feet the middle ring connects with the exterior ring, making the masonry at that point 36½ inches thick; it is then 20 inches thick for an additional height of 60 feet; 16 inches thick for 70 feet; and 12 inches thick thence to the enlargement for the chimney head. The core is uniformly 12 feet inside diameter to the top, the first 100 feet being 16 inches thick; then 12 inches thick for 60 feet; then 8 inches thick for 90 feet; and then 4 inches thick for 29½ feet to the top. It is entirely separate from the outside masonry except about the door-ways and openings for the flues. The core was laid in mortar of lime and sand; the outside shell in lime, cement and sand.

A description was then given by Dr. Charles E. Emery, M. Am. Soc. C. E., of the construction of the chimney built under his direction, of the Greenwich Street Boiler House of the New York Steam Heating Company. This chimney was a creature of circumstances, it being necessary to place within a very limited area, a very large boiler capacity, viz., 16,000-horse power. This was done by making four stories of boilers —the chimney was therefore necessarily located with reference to these boilers, and the plan of the chimney was determined by the shape of the lot. The beach of the Hudson River was at some time at this locality, and the foundation of the chimney was placed in fine clear beach sand with some packets of coarser sand and a little stone. The foundation is one foot below high water. The chimney is 27 feet 10 inches in the clear inside, and 8 feet 4 inches wide. The height is 220 feet above high water—221 feet above the foundation.

Mr. F. L. Griswold, M. Am. Soc. C. E., described a chimney erected in Mexico for a cotton factory about 160 feet high, which had been in use for over 12 years, which was built of apparently sun-dried bricks, and which seemed to be now in excellent condition. This chimney was built by Indians and seemed to be very symmetrical and well made. The bricks were about 10x3x7.

Mr. H. W. Brinkerhoff, M. Am. Soc. C. E., described a chimney constructed of old rails, which was in successful use in Pennsylvania. It was generally known as a Crinoline chimney.

Mr. Wm. E. Worthen, M. Am. So. C. E., referred to several chimneys built by him, and expressed a doubt as to the necessity of very great height in chimneys.

ENGINEERS' CLUB OF PHILADELPHIA.—Record of regular meeting, February 16, 1884.

Mr. Chas. A. Ashburner detailed his experience in the use of Aneroids in Leveling. He exhibited a collection of various forms of instruments and described their advantages and errors, and the means of correcting the latter, the graphical method being specially recommended.

The Secretary presented, from Mr. Edwin Ludlow, a description of the Exhaust Injector, with results of experiments therewith.

The Secretary presented, from Prof. J. A. L. Waddell, an illustrated paper upon Lateral Systems for Iron Pratt Truss Highway Bridges. The accompanying tabular data are based upon a lower than maximum wind pressure, upon the assumption that travelers do not venture upon highway bridges during gales of maximum velocity, and could not escape injury if they did, even if the bridge were proportioned as he considers railroad bridges should be, for maximum wind pressure when covered by a train. In the same connection the relative inconvenience of loss of highway and railroad bridges is also considered.

MARCH 1st, 1884.—President Ludlow described tests of the crushing strength of ice which were made by him in order to learn, approximately, the strength required for an ice harbor of iron screw-piles, in mid-channel, at the head of Delaware Bay. Eighteen pieces were tried with government testing machines at Frankford, Philadelphia, and at Fort Tompkins, Staten Island. The specimens were, carefully prepared 6 inch and 12 inch cubes, and roughly cut slabs about 3 inches thick, of different qualities and from different localities. For pure Kennebec ice the lowest strength obtained was 327 pounds, and the highest 1,000 pounds per square inch. For inferior qualities the strengths varied from 235 to 917 pounds. The higher results were obtained, generally, when the air temperature in the testing room was from 29° to 36° F.; as against 55° to 68° F. for the lower results. The pieces generally compressed ½ to 1 inch before crushing.

The Secretary exhibited for Mr. C. A. Ashburner a set of blues of some yet unpublished details of the Chicago Cable Railways.

The Secretary presented a note, by Prof. W. S. Chaplin, upon a prevalent error in data given for determining the true meridian, by observing the instant at which Polaris and Alioth come into the same vertical, and then following Polaris for a *certain time* at the expiration of which it is said to be on the meridian. He gives, as the true time, the following: Latitude 40°, 25 minutes, 36 seconds; Lat. 50°, 25 m. 24 s.; Lat. 60°, 25 m., 5 s.; Lat. 70°, 24 m. 29 s.

Mr. C. J. Quetil, visitor, exhibited models of the Wire Truss recently described by him.

Prof. Mansfield Merriman presented a statement of the progress of the triangulation carried on in Pennsylvania by the United States Coast and Geodetic Survey, and exhibited a map showing its present condition. The stations located are twenty-seven in number, of which nineteen have been occupied for the measurement of angles. These are in the southeastern part of the State, in the Counties of Bucks, Montgomery, Delaware, Chester, Lancaster, York, Dauphin, Lebanon, Berks, Lehigh, Northampton, Monroe, Carbon and Schuylkill. The geographical positions of the stations have been computed from two of the sides of the primary cost triangulation, one near Elkton, Md., and the other near Trenton, N.J., which serve as bases for the work thus far executed.

ENGINEERING NOTES.

THE leading organ of German free trade, commenting on the recent discussion in the Chamber of Deputies on the coalition of the steel rail works, remarks that since the new iron duties came into operation in 1879, the German steel works have drawn about sixty millions of marks from the ratepayers in the shape of subventions. That is to say, that almost invariably, when quoting for foreign contracts, German steel manufacturers have quoted about 30 to 60 per cent. less than they charged for the same goods to German railways, being enabled by the heavy customs duties to take advantage of the latter.

THE Danube Regulation Committee has decided to spend the sum of 1,488,000fl. on works of regulation along the river in 1884. These works will extend from Stein to Deutsch-Altenburg, on the Hungarian frontier. The chief of them are the continuation of the inundation dikes below Vienna, to which 600,000 fl. are to be devoted, and the great regulation works at Deutsch-Altenburg, on which, as a first instalment, 168,000fl. are to be expended this year. According to the opinion of experts, the imperfections experienced near Vienna are entirely owing to the works not having been carried out to a sufficient distance down stream.

A JOINT for driving bands, in which great strength is combined with an even surface, has lately been offered to the public, although it has been used privately for upwards of five years. Messrs. Bailey Bros., of Chancery Lane, were applied to by a large firm of mill-band makers to supply a cement, so modified from that which they have long made for mending china and glass, that it might be used for joining machine belts. The ends of the belt to be joined are cut to a long scarf, not, however, so long as the width of the belt. The cement is supplied hot, the two parts are put carefully together and the joint is subjected to pressure from a weight or in a vice. The joint becomes set in twelve hours; but it is preferable not to use the belt before twenty-four hours have elapsed, when, it is said, the joint is the last place at which the belt will break. The practice is to suspend the belt, with a heavy weight on the joint, for the double purpose of testing the joint and of stretching the belt. We are assured that the joint will stand both heat and damp, and that one has never been known to give way.

THE trial at Lyons has been announced of a large dredger for the Corinthian Canal, which is to connect the Gulf of Athens with the Lepanto. This canal, according to measures more recently given in continental journals, is 7600 metres in length, 8 metres deep, and 23·5 metres in width. Amongst the largest dredgers in use on the works are two, one of which has, as above stated, been recently tried by the makers, MM. Demange et Satre. Each dredge is to extract 5000 cubic metres of material per day of ten hours; the buckets each have a capacity of 750 litres. A compound engine of 300-horse power raises fourteen of these buckets per minute. The hulls of the dredger were made by M. Debianne at Vaise. At the trial, M. de Lesseps is said to have expressed himself so astonished with the quantity of work done by it that he means to have the same kind to dig out the central parts of Africa so as to make that central sea, which, says a French paper, "he has in preparation with his ordinary activity—without neglecting the Suez Canal or the works at Panama– and which is to crown his career according to the opinion of the Grand France."

THE Macquarie Lighthouse, at the entrance to Port Jackson, is one of the largest and finest in the world; it is also the finest example of electric lighting of which the southern hemisphere can boast. It was commenced on March 1st, 1880, and the light in connection with it was brought into operation on 1st June, 1883. The old lighthouse, which the new one has replaced, was built in 1816, and was the first structure of the kind in the southern hemisphere. The light is of the first order, a sixteen-sided, dioptric, holophotal revolving white light, of the system of Teulere, commonly attributed to Fresnell, showing a flash of eight seconds in every minute, and having a range of twenty-five miles seaward. It is, however, discernible for a considerably greater distance, owing to the luminosity produced in the atmosphere by the electric beam before the direct rays become visible. It was constructed by Messrs. Chance Bros. & Co., of Birmingham, under the supervision of Sir Jas. N. Douglass, engineer to the Trinity Board. The lighthouse is fitted with gas and oil apparatus as well as electric light. The Macquarie Lighthouse is intended only to illumine half the horizon, it is therefore possible to make use of the landward rays by means of a dioptric mirror. This is probably the first instance of the use of a dioptric mirror for an electric light.

IRON AND STEEL NOTES.

THE BESSEMER STEEL INDUSTRY OF GREAT BRITAIN IN 1883.—The following report has just been published by the Secretary of the British Iron Trade Association, Mr. J. S. Jeans.

The total production of Bessemer steel ingots in the United Kingdom in 1883 was 1,553,380 tons, against a total of 1,673,649 tons in 1882. This amounts to a decrease of 120,269 tons, or 7 per cent.

It is probable that 1883 was the first year during which there was a decreased production of Bessemer steel in the United Kingdom since that industry became fairly established. It is, at any rate, the first year that has shown a decrease since 1878, when the returns of the production were first collected by the British Iron Trade Association, as the following figures show :

Production of Bessemer Steel Ingots in the United Kingdom in each year from 1878 *to* 1883, *both inclusive.*

Year.	Make of Ingots, Gross Tons.	Year.	Make of Ingots, Gross Tons.
1878.....	807,527	1881.....	1,441,719
1879	834,511	1882.....	1,673,649
1880.....	1,044,382	1883.....	1,553,380

The principal decrease of make in 1883 has taken place in the Sheffield district, and is, of course, due mainly to the removal of one of the largest works to another part of the country. In the Cleveland district the decline of 25,018 tons is mainly due to labor difficulties.

The production of Bessemer steel rails in the United Kingdom in 1883 was 1,097,174 tons, against 1,235,785 tons in 1882. There has therefore been a diminished make of 138,611 tons in 1883.

RAILWAY NOTES.

An electric locomotive, fitted with the apparatus of Mr. Leo Daft, is now running experimentally on the Saratoga, Mt. McGregor and Lake George Railway, a somewhat steep and crooked 3 ft. gauge line 10 miles long, laid with 32lb. rails. The following particulars are given in the *Electrician and Electrical Engineer:* "A mile of this road was fitted for electric operation by tightening the joints of the existing track, and laying a special middle rail or conductor upon wooden blocks, which were saturated with pitch. Starting from the terminus the track ascends gradually for 600 ft., and then descends for 2,000 ft. more, when a sharp curve and an ascending grade of 93 ft. to the mile is encountered. The electric motor is designed for heavy work. It bears the name of 'Ampére.' The motor is 9 ft. 6 in. long, 5 ft. wide, stands 3 ft. above the rails, and weighs 4,500 lbs. The armature and field magnets are inclosed in a box at the rear of the platform, in front of which is the driver's seat, and a dashboard carrying three controlling switches and a keyboard. The right switch makes and breaks the current, the left switch controls an electric brake, and the center switch and keyboard control the combinations of the coils of the motor answering to the cut-off of the steam locomotive. The reverse lever is on the right. Two phosphor-bronze wheels press firmly upon the center rail by the action of a spring upon their pivoted supports. The current passes from this rail through the wheels to the switches and keyboard, thence to the electric engine, and through the driving wheels to the outer rails. The generators are two in number, of Mr. Daft's manufacture, each occupying a space 5 ft. by 4 ft., and weighing 1,200 lbs. They were driven by a 25 horse-power Fitchburg engine, and the current led thence to the rails—a distance of about 200 ft.—through underground conductors. On the day of the trial the motor was attached to an ordinary 10-ton passenger coach, into which sixty-eight passengers—nearly double its ordinary capacity—were crowded, while the motor carried six more, making a total load of about 17 tons. The 'Ampère' started slowly, but surely, and ran to the end of the mile without stopping, at the rate of about 8 miles an hour. Descending the 93 ft. grade on the return trip, a considerable speed was attained, causing the motor to jump the track at the curve, by which accident its running gear was slightly damaged. The trip was made in the presence of nearly 2,000 spectators, many of whom amused themselves by trying to obtain shocks from the track. But the sensation was found to be scarcely perceptible. Since the first trial the 'Ampere' has been run in wet and snowy, as well as dry, weather, with satisfactory results. The results of this trial show that an electric locomotive under perfect control, weighing 2 tons, will haul an ordinary passenger coach, weighing, with its load, 15 tons, over heavy grades and sharp curves at a speed of eight miles per hour, by means of an electric current, generated by a 25 horse-power engine, and transmitted one mile."

ORDNANCE AND NAVAL.

New Cruisers.—The Senate, by a vote of 38 to 13, passed the bill for the construction of steel cruisers for the navy on Feb. 29th. The bill as passed authorizes the President to direct the construction of seven steel vessels for the navy, consisting of one cruiser of 4,500 tons displacement, one cruiser of 3,000 tons, one dispatch vessel of 1,500 tons, two heavily-armed gunboats of 1,500 tons each, one light gunboat of 750 tons, and one gunboat not to exceed 900 tons. It further authorizes the construction of one steel ram, one cruising torpedo boat, and two harbor torpedo boats. It provides that the Naval Advisory Board shall examine all the plans, specifications and contracts, and materials for the vessels, and shall give the Secretary of the Navy advice and assistance thereon, but that the Board shall have no authority to enter into contracts; that no contract shall be entered into until full and complete plans and specifications shall have been prepared and approved in writing by the Board or a majority of its members.

Mr. C. Moller's steamship circular for January says, the extraordinary amount of tonnage which has been constructed during the last three years both in this kingdom and abroad has far exceeded the requirements; and although many new trades have been opened and the losses been very heavy, it has become impossible to find profitable employment for many of the ships now afloat. Instead of laying them up in the same way as the sailing vessels used to be in former times during dull periods, owners have kept them running at freights which, in many instances, left a loss, and the result has been amply verified by the small dividends received by the shareholders. During the past year no less than 720 steamers with a total of 1,102,801 tons, were added to the mercantile fleet in the United Kingdom alone, and if to this be added 674 steamers of 982,961 tons, built in 1882, and 630 steamers of 925,000 tons in 1881, we obtain the respectable total of 2,024 steamers and 3,010,762 tons in three years. And although small in comparison, yet the number of ships constructed on the Continent, especially in France, Sweden and Germany, form also a not inconsiderable fleet.

The Armament Question.—A lecture on this subject was delivered at the Royal United Service Institution by Captain C. O. Browne, R. A.; this officer occupies the position of lecturer on armor plates at Woolwich, and he may therefore be looked upon as an authority on the subject.

The lecturer commenced by stating that his chief object was to call attention to features in the position of the armor question that were peculiar and of importance. He then proceeded to give the data on which he based his arguments, and which were the results of experiments carried out at Meppen in March, 1882; at Spezzia at the end of 1882; at St. Petersburg at the beginning of 1883; and at Shoeburyness in August and September, 1883.

We can summarize these trials as follows:

At Meppen the trials were of perforation of soft armor.* A 110 lb. shot, with a velocity of 1,749 ft., and striking energy of 2,330 foot-tons, went through a target of two 7 in. wrought iron plates, with 10 in of wood between them, and passed on over 800 yards, uninjured. This projectile would probably have penetrated 11½ in. of wrought iron, and the extra 3 in. accomplished here is due to the two plates being so far separated. The same gun fired at 35 deg. to the normal, against an 8 in. plate, with 10 in. backing of wood, penetrated. There were also trials made of large bursting charges, and stronger envelopes for common shell.

At Spezzia the trials were of hard armor steel-faced plates, 19 in. thick, from Cammell & Co. and Sir John Brown & Co., and steel plates from Creusot. The 100-ton gun was used, and the result of two rounds on each target was decidedly in favor of the Schneider steel.

The St. Petersburg trials were carried out between Cammel's steel-faced armor and Schneider steel plates, 12 in. thick, an 11-in. gun being used. The result of three rounds was that the latter plate fell to pieces, while the former target had by far the best of it.

The experiments carried out by our engineers were to ascertain the protection afforded to granite walls by iron plates. The 80-ton gun was used, the targets being of 2.8 in. iron plates with 5 inches of wood between them, and 12 in. Wilson's steel-faced iron.

The battering projectile from the 80-ton gun passed clean through the plate and 10 feet into the masonry beyond. Another round being fired at the 12-in. plates broke up in the iron. This projectile was supposed to be capable of penetrating 25 in. of iron. The fact of a 12-in plate being able to keep it out must, the lecturer considered, be attributed to the hard granite backing.

Captain Browne then went on to discuss our system of calculating effects. In Russia, Italy and England the blow is estimated on the power of the shot to perforate, and this, he says, is true enough when wrought iron is the target, but where steel faces are used, and perforation is not effected, the action is more that of a pointed wedge striking and splitting the plate before it has entered very far. The effect would probably be proportional to the total energy of the blow delivered, but without reference to the full diameter of the shot, which never comes into play; thus the advantage of a small diameter would not be apparent. With a steel-faced target the shot are generally matched against the plate on two standards. On the lower one the shot has just sufficient power to perforate wrought iron of the same thickness. On the higher standard it has sufficient penetrating power to perforate a wrought-iron plate of perhaps 20 per cent. more thickness than the plate. The lecturer illustrated his meaning by the following example:

A 9-in. Woolwich gun and 5¾-in. Krupp were fired in comparison; the former had 118 foot-tons of energy per inch circumference, and the latter 123. Their penetration, according to the wrought-iron standard, would therefore be about the same, but their total energies were respectively 16,400 and 5,800 foot-tons. It seems absurd that these two should be taken as having the same effect on steel armor. The lecturer then illustrated his meaning practically with three bullets of the same weight, shaped like punches, with diameters of ¼ in., ½ in. and 1 in. respectively. His object was to test the two systems by comparing the projectiles. The equation of drop being $W h = \pi D t^2 K$, where

W=weight
h=height of fall
D=diameter of projectile
t=thickness of sheet punched
K=some constant,

it follows that everything else being constant the height from which the projectiles must be dropped in order to perforate a soft material will vary with the diameter. The experiment was then shown as follows: A piece of felt was used as representing the soft armor, and the 1 in. diameter projectile perforated it when dropped from a height of 60 in.; the projectile with the ¼ in. diameter being then substituted, it was found that a drop of 15 in. sufficed for perforation. In order to show the difference in the case of hard plates, brick was taken as the material, and the ¼ in. broke it from a height of 19 in.; the same weight of projectile with the 1 in. head broke another similar plate from 25 in., hence the law of perforation cannot be taken as giving a measure of the relative powers of the projectile in this case. The lecturer then proposed, as a check on the perforation standard, to divide stored-up work by the number of tons in each plate and thus get the shock per ton of plate. He admitted, however, that the question is full of difficulties, and that it is by no means easy to fix a fair standard.

Turning to the consideration of projectiles, he maintained that more experiments should be tried with our projectiles against foreign armor, such as Gruson's, and that we should ourselves further the manufacture of steel projectiles by all means in our power. He attributed the hanging back of the manufacturers in submitting steel projectiles for trial, to their inability to obtain plates to test these projectiles on beforehand. Hence, when the projectile is submitted it is really only in an experimental state, and manufacturers are not willing that their reputation should be endangered in this way. He suggested that plates left from previous experiments should be used for this purpose. As a matter of fact, we understand that this has already been done with the plates tested in the Nettle at Portsmouth.

Captain Browne considered that experiments

* By soft armor is meant that which yields to perforation. By hard armor that which cannot be perforated, but is destroyed by breaking up.

against hard armor are specially needed in this country, and maintained that our service projectiles have never been tried against either Schneider steel or Gruson's chilled iron. As the lecturer very wisely remarked, it is against foreign armor we will have to contend, and therefore our projectiles should be capable of damaging it. He said that Krupp had tried chilled projectiles against Gruson's armor, and they failed to do anything, simply breaking up, and that eventually he had to use steel shot. Finally, the lecturer summed the points of his lecture as follows:

1. The need of a better system of estimating effects on hard armor.

2. The need for developing the manufacture of steel projectiles.

3. The necessity of making trials against Gruson's or other very hard armor.

An animated discussion followed, in which Admirals Boys, Hamilton and Selwyn, Sir Chas. Nugent, Captain McKinley, R.A., and Mr. Walter Browne took part. Nothing throwing much light on the points raised came out in this discussion. Admiral Selwyn considered that the principle of the anvil was the one we ought to go on, but Mr. Walter Browne and the lecturer in his reply did not think the two cases analogous. It appears to us that all the lecturer's points are worthy of serious attention. Krupp appears to have manufactured good steel projectiles, and there is certainly no sound reason why we should be behindhand in this matter.

STEEL DECKPLATE TRIALS.—Further experiments with steel deckplates have taken place at Eastney. The targets in this instance consisted of five two-inch armorplates, strongly set in a wooden frame and placed at a slight angle to the line of fire. They were attacked with the 9-inch muzzle-loader, with uniform battering charges, each plate receiving a couple of rounds. Considering the severe test to which they were subjected at a range of about 100 yards, the targets withstood the ordeal remarkably well. One place only succumbed to the attack, the damage being inflicted apparently by the blow of the butt end of the projectile as the point glanced off. Two of the plates were not perforated, the graze of the shot where it struck and glanced off to sea being only marked by a well-defined bulge. The result of the experiments demonstrates the advantage which is likely to attend the peculiar contour which has been given to the under-water deck of the *Imperieuse*.

RECENT TRIALS OF MACHINE GUNS.—Some doubts having been expressed as to the accuracy of the published results of the trials instituted by the Greek government with the Nordenfelt 1½-inch machine shell-gun at Athens in May and June last, on which occasion this gun succeeded in penetrating a 3.4-inch target (made up of several thinner plates), at a range of 210 yards, further experiments were made with a similar weapon at Dartford, on October 16, in the presence of numerous foreign attaches, colonial representatives, and others, the particulars of which we (*United Service Gazette*) herewith give. The Nordenfelt 1½-inch gun, placed at a distance of 50 yards, was fired against a target made up as follows: Four iron plates, with an aggregate thickness of 2.68 inches; five steel plates, with an aggregate thickness of 0.59 inch; thus the total thickness of the compound target was 3.27 inches. The steel bullet fired from this gun completely penetrated this target, and buried itself to a depth of four feet in the sand butt behind. This result confirms in the most practical and conclusive manner the accuracy of the Greek experiments. Further confirmation of the great penetrative power of the Nordenfelt 1½-inch gun is afforded by the official trials, which have been lately carried out in Roumania and in Brazil. The Brazilian target No. 2 was formed of four ½-inch iron plates, with a space of 15½ inches between the first and second and second and third, the last two plates being placed close together. All the targets were easily perforated, with the exception of the Brazilian 4-inch solid iron one; in the latter case the steel bullet entered the plate to a depth of 2.7 inches. An ordinary 9-pounder gun was also fired against this 4-inch plate at the same range, but only penetrated 2.28 inches, showing nearly ½ inch less penetration than the Nordenfelt 1½-inch gun, which throws a projectile of 1.75 lb. weight. In the Roumanian trials the accuracy of fire of the Nordenfelt 1½-inch gun was also tested with the following results: At a range of 1,432 yards 14 out of 15 shots hit the target, fired with deliberate aim, with a mean deviation of 12 inches, and at a range of 820 yards 16 out of 22 shots, fired as rapidly as possible, struck the target, 16 feet by 16 feet, the aim being unaltered after the first shot. In the Dartford experiments the rapidity of fire of this Nordenfelt gun was also tested, on which occasion seven shots were fired in 12 seconds, and six shots in 10½ seconds, or at the rate of 35 shots per minute. Further, it was shown how easily and rapidly the mechanism of this machine gun, consisting of only ten pieces, could be taken to pieces and put together, the times being respectively for each operation 24 seconds and 64 seconds. Another very important question was also considered at the late Dartford trials, viz., the possibility of firing Boxer cartridges from rifle calibre machine guns. Two series of 100 rounds of Boxer ammunition were fired from the Nordenfelt 10-barreled gun, each in seven seconds; and from the Nordenfelt 5-barreled gun 150 rounds of the same ammunition were fired in twelve and six seconds respectively; that is for the former weapon a rate per minute of 855 shots, and for the latter one of 500 shots, which must be considered satisfactory when the nature of the cartridges used is considered. The importance of these experiments lies in the fact that the Boxer cartridge must remain for some years longer as the ammunition for the Martini-Henry rifles used by our volunteers, Indian and colonial forces, and also for some considerable time as the rifle ammunition of our regulars at home. Recently, by order of the Sultan, trials of the Nordenfelt gun took place at Tchataldja, in presence of a committee composed of His Excellency Ristow Pasha, three generals of artillery, and Mehemet Bey, Edham Bey, and Ali Bey (captains in the Imperial Ottoman navy).

In the trials the target, composed of four plates of Cammell's compound, was placed at the distance of 500 meters, when the bullets penetrated three of the plates and smashed the fourth. Amongst the trials for precision, one of the most important was at 2,000 meters, against a target 5 meters square. At this long range the result was most satisfactory, two of six shots having struck. The report of the committee has not yet been submitted to his majesty, but it is understood that the adoption of the Nordenfelt gun will be recommended for the Turkish navy, as it is the only one satisfying the conditions required for modern warfare, especially in its defensive power against torpedoes. We published the results of a series of trials with Nordenfelt guns, which took place at Dartford on July 26, in *Iron* of August 10.

BOOK NOTICES

THE CREATORS OF THE AGE OF STEEL. By W. T. Jeans. London: Chapman & Hall.

This is a series of short biographical sketches of modern workers and inventors in the field of metallurgy of iron and steel.

The greater portion of the work is devoted to Sir Henry Bessemer, Sir William Siemens and Sir Joseph Whitworth. A less amount of space is awarded to Sir John Brown, Mr. S. G. Thomas and Mr. S. G. Snelus.

The whole is related in a pleasing style, omitting irrelevant details, and reciting fully the successive steps of development of the important inventions and discoveries.

The book is without illustrations; the topography is good.

A BIBLIOGRAPHY OF ELECTRICITY AND MAGNETISM, 1860 TO 1883, WITH SPECIAL REFERENCE TO ELECTRO-TECHNICS. Compiled by G. May. London: Trubner & Co.

A convenient hand book for scientific writers. The index is classified under the languages in which the works are written, and enables, therefore, the reader to find under one heading all works on any specialty.

Although prepared for students, mere school books are omitted from the list.

ABSOLUTE MEASUREMENTS IN ELECTRICITY AND MAGNETISM. By Andrew Gray, M.A., F.R.S.E. London: Macmillan & Co.

This book is not offered as a full treatise on Electrical and Magnetic Measurements, but is designed to give a clear account of the system of absolute units as now adopted, and of some methods and instruments by which the system can be applied in practical work.

Separate chapters treat of Determination of the Horizontal Component of Earth's Magnetic Field, Absolute Unity of Magnetic Pole and Field, Measurement of a Current in Absolute Units, Definition of Absolute Units, and Derivation of Practical Units, Graded Galvanometers and their Graduation, Potentials in Derived Circuits, Comparison of Resistances, Measurement of Energy in Circuits, Measurement of Intense Magnetic Fields, Dimensions of the Units of Physical Quantities.

ELECTRIC LIGHTING: ITS PRINCIPLES AND PRACTICE. By A. A. Campbell Swinton. London: Spottiswoode & Co.

A summary of the methods at present employed in Electric Lighting is a convenience to any reader of current scientific literature. The author of this treatise begins by an elucidation of the theory of the production and transmission of Electric Energy, defining accurately the technical terms, and describing with precise phraseology the mechanical appliances which are common to all devices employed for such purpose. The question of quantitative measurements of electricity is next treated in a satisfactory manner. The "Sources of Power" for Electric Machines occupy but little space, and deserve perhaps less. The *principles* of the various Dynamo Machines are presented without mention of the bewildering complexity of mechanical details, which so often obscures the description in current technical literature.

Arc Lamps and Incandescent Lamps are next treated, and with full descriptions of all the devices that have sufficiently stood the test of trial to deserve mention.

"Accumulators" are briefly described, and then "arrangement of the different complete systems," and "applications, advantages and cost" complete the work.

The book deserves success for the clear, concise treatment of an interesting but technical subject.

TOPOGRAPHICAL SURVEYING. Science Series No. 72. By Geo. J. Specht, Prof. A. S. Hardy, John B. McMaster, C.E., Henry F. Walling, C.E. 18mo. Price 50 cents.

It is seldom that so much that is valuable to the student of surveying is found in so small a compass.

The separate parts were originally prepared as contributions to this magazine, and while compactly written in the interest of economy of space, they were full enough to clearly set forth the newer methods of surveying.

The Stadia method is fully described in Mr. Specht's article, and the proper time and method of its application clearly explained. This method is now widely used in general surveys. Prof. Hardy's essay is an elucidation of the method of topographical surveying as practiced in France: that the author is a master of the art of teaching this essays plainly shows.

Mr. McMaster's portion of the book relates to special cases that frequently occur in any general survey. As neat applications of Modern Geometry they are no less interesting than useful.

The last essay is a valuable contribution to science from a surveyor of wide experience in the art of measuring large areas, with reference to the correct delineation on maps.

The illustrations of this little book are numerous and good.

MULHALL'S DICTIONARY OF STATISTICS. By Michael G. Mulhall, F. S. S. London: George Routledge & Sons.

The author, in a brief preface, says: "Hitherto every science has had its Dictionary except Statistics," and claims this is the first Statistical Dictionary in any language.

The subjects are presented in alphabetical order, beginning with Abbeys and ending with Zinc Industry. Variable statistics are presented for several dates ending with 1880.

Statistics relating to Debts, Banking, Steam Power, Cattle Raising and money are represented graphically by full-paged colored diagrams.

It is a book which a large number of people, whether writers, teachers or students, may find exceedingly useful.

MISCELLANEOUS.

M. MAUSER has succeeded in sending a telephonic message to 100 listeners at the same time, at a distance of 250 kilometres—155 miles—namely, from Paris to Nancy. This he is said to effect by the use of stronger currents than usual, but this must involve special construction of the telephone.

DR. HAMMERL has devised an ingenious method for measuring the intensity of the light of electric lamps, by which the necessity for placing them at a great distance from the standard candle is avoided. He interposes a revolving disc, in which are cut out sectors, allowing only a portion of the rays to pass. For instance, if the sum of the angles of the sectors be 180 deg., half the light will be intercepted. It has been found that three sectors are sufficient to give a uniform light with a moderate speed of rotation. Consequently, to reduce the light to a third three sectors of 40 deg. are employed. With three sectors of 12 deg. the light is reduced to one-tenth of its actual power. By employing two discs, each provided with three sectors of 60 deg. cut out, and arranged one behind the other on the same axis, they may be made to give as great a reduction of the luminosity as may be desired.

IN an article on Gutta-Percha in the *Journal of the Society of Arts*, Mr. James Collins says:—"Dr. Oxley calculated that to supply the 6918 piculs—1 picul equal 133⅓ lb.—exported from Singapore, from the 1st of January, 1845, to 1847, 69,180 trees were sacrificed; and, according to the *Sarawak Gazette*, 3,000,000 trees were required to supply the 90,000 piculs exported from this district during 1854 to 1874. These are only two instances, the first showing the trade in its infancy; and the second, that of a limited and comparatively small locality. In fact, the gutta-percha tree has only been saved from utter annihilation because trees under the age of twelve years do not repay the trouble of cutting down. Still, it is clear that the growth of young trees of the best varieties has not kept pace with the destruction, but are becoming much scarcer, so that recourse now, more than ever, has to be had to the products of very inferior varieties. At the present time there is a great difficulty in obtaining sufficient supplies of the best varieties, especially for telegraphic purposes. The Indian Government, acting on the advice of the late Mr. Howard, F.R.S., Mr. Markham, Dr. Spruce, and others, have taken up the india-rubber question. The Colonial Government should now take up the question of gutta-percha."

A PIGMY voltaic battery of great power for its size has been devised by M. Skirwanov, and is now employed to furnish the star lights on the heads of the ballet of "La Farandole," Paris. The *Times* says, it gives an ampere for one hour, and has an electro-motive force of 1.45 volts. Two of these cells, contained in ebonite cases buckled to the belt of the performer, keep a star light going, and the light is readily controlled by the wearer. Each cell consists of a zinc plate bent into the form of a U, and holding in its inside a plate of silver, surrounded by chloride of silver, as in the ordinary De La Rue chloride of silver cell used by electricians for testing purposes. The zinc plate forms one pole of the cell and the silver the other. A solution of caustic potash—75 parts potash to 100 water—is filled in, and as a porous diaphragm, the chloride of silver is covered with parchment paper. The vessel is of ebonite, with closed mouth, which, however, is opened when fresh liquid is put into the cell. This is necessary after every hour's run, and the chloride of silver has to be replaced after three or four hours of use. The cell is thus expensive, but this is of minor importance in theatrical work as compared with its small size and weight—100 grammes.

WILL electricity enable us to transmit power in large quantities more efficiently than other means? Will it enable us to transmit small quantities? These questions were put to the Society of Arts, and answered by Professor Osborne Reynolds in his Cantor lectures as follows: Thanks to the experiments of M. Deprez, we can say that a current of electricity, equivalent to 5-horse power, may be sent along a telegraph wire $\frac{1}{6}$-inch in diameter, some ten miles long—there and back—with an expenditure of 29 per cent. of the power, because this has already been done. Compared with wire rope, this means falls short in actual efficiency, as Messrs. Hems send 500-horse power along a $\frac{3}{4}$-in. rope. To carry this amount, as in the experiment of Deprez, 100 telegraph wires would be required; these wound into a rope would make it more than 1.4in. in diameter, four times the weight of Mr. Hems' rope. With the moving rope the loss per mile is only 1.4 per cent., while with the electricity it was nearly 6 per cent.; so that, as regards weight of conductor and efficiency, the electric transmission is far inferior to the flying rope. Nor is this all. With the flying belt, Mr. Hems found the loss at the ends, in getting the power into and out of the rope, 2½ per cent.; whereas, in M. Deprez's experiments, 30 per cent. was lost in the electric machinery alone, which is very small as such machinery goes. But this is not all. No account is here taken of the loss of power in transmission to and from the electric machinery. Taking the whole result, it does not appear that more than 15 or 20 per cent. of the work done by the steam engine could have been applied to any mechanical operation at the other end of the line, as against 90 per cent. which might have been realized with wire rope transmission. To set off against this, electricity has the enormous advantage in the conductor being fixed, and in the fact that it is likely to be, if anything, less costly and more efficient for small quantities of power than for large.